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NASA Technical Memorandum 86234

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Fundamental Remote Sensing Science Research Program 1985 Summary Report of the Scene Radiation and Atmospheric Effects Characterization Project

by
D. W. Deering

September 1985

(E86-10011 NASA-TM-86234) FUNDAMENTAL REMOTE SENSING SCIENCE RESEARCH PROGRAM: THE SCENE RADIATION AND ATMOSPHERIC EFFECTS CHARACTERIZATION PROJECT Summary Report, 1985 (NASA) 195 p HC A09/MF A01 CSCL 05B G3/43

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by
D. W. Deering

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PREFACE

Following a decade of research in the application of remote sensing technology to earth resources measurement and monitoring with earth observing satellites, the National Aeronautics and Space Administration found a need developing for the advancement of our understanding of the physical processes associated with the remote sensing. Therefore, at the beginning of the 1980s NASA established a continuing research program in fundamental remote sensing science that would enhance our ability to learn more about the physical and biological processes of our planet from space acquired data and would contribute to a base of scientific understanding needed to support the planning of new and effective sensors and flight programs. The Scene Radiation and Atmospheric Effects Characterization (SRAEC) Project was established within this program to improve our understanding of the fundamental relationships of energy interactions between the sensor and the surface target, including the effect of the atmosphere.

This report has been prepared to provide a very brief overview of the SRAEC Project history and objectives and to report on the scientific findings and project accomplishments. An attempt has been made to elucidate the overall project progress and accomplishments through principal investigator team introspection, and the principal investigators have prepared succinct summaries of their individual study results achieved since the project's initiation just over three years ago.

A meeting of the PIs is conducted annually to bring the scientists together to present and discuss their results with one another. This annual summary report derives from the most recent annual meeting held at the Massachusetts Institute of Technology in Cambridge, Massachusetts during January 29-31, 1985. The overall program management is under the direction of Dr. Robert E. Murphy of NASA Headquarters, Code EE, Washington, D.C.

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FUNDAMENTAL REMOTE SENSING SCIENCE RESEARCH PROGRAM

1985 SUMMARY REPORT OF THE
SCENE RADIATION AND ATMOSPHERIC EFFECTS CHARACTERIZATION PROJECT

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I. SRAEC PROJECT BACKGROUND

I.A. SRAEC PROJECT ORIGIN AND OBJECTIVES

During the "Landsat Era" of the 1970's, the development of rapid, empirical approaches to satellite data interpretation took precedence over the development of a full scientific understanding of the earth-atmosphere scene radiation complex. The importance of synoptic remote measurements of the earth's surface and the atmosphere has been clearly demonstrated, but the need to more fully utilize the powerful satellite remote sensing measurement potential has led to the realization that purely empirical techniques are no longer sufficient.

Significant advancements in both remote sensing components and systems and in the remote sensing derived understanding of physical and biological processes on the earth's surface require increased understanding of the characteristics of earth scene radiation and atmospheric effects at visible, infrared and microwave wavelengths. Thus, NASA established the Fundamental Remote Sensing Science Research Program within the Land Processes Branch of the Earth Science and Applications Division at NASA Headquarters.

The Scene Radiation and Atmospheric Effects Characterization Project is conducted as the primary element of the program with the general goal being to improve our understanding of the energy emitted or reflected from an earth surface target, through the intervening atmosphere as measured by a remote sensing system. Emphasis has been placed on theoretical model development with some observational studies and empirical characterizations relating electromagnetic energy reflected and emitted from earth

surfaces to their biophysical characteristics.

Fundamental research needs for future applications research in aerospace remote sensing were identified through a series of workshops during fiscal year 1980 that involved leading scientists from universities, industry and government. The research issues that were identified through these workshops and reported as a final report to NASA Johnson Space Center (under NAS 9-16016) in August 1980 are summarized in last year's annual SRAEC report (NASA Technical Memorandum 86078, March 1984) and, therefore, are not repeated here.

Proposals from organizations outside NASA were solicited in July 1981, and following a NASA Headquarters conducted peer review, sixteen investigations were funded during fiscal year 1982. Most of these were proposed as three-year studies, such that this annual report reflects the end-of-study results for many of the principal investigators. Since the initial call for proposals, other unsolicited proposals have been received and peer reviewed. Therefore, there are a few principal investigators who have only recently begun their studies under this project. Even though there is finite funding available, proposals for new research are continually encouraged, especially in those topical areas that were identified in the early planning phase as being important research issues that have yet to be adequately addressed.

The product of the SRAEC project is an improved understanding of the physical radiant energy interaction (remote sensing) processes through measurements and modeling that will ultimately

enable the proper specification of earth observing space sensor systems and the measurement and modeling of the important physical, chemical, and biological processes and their interactions. The success of the individual scientists in the program is measured by the quality professional papers that are produced and contributed through refereed scientific journals.

I.B. PRINCIPAL INVESTIGATOR WORKSHOPS

Following the selection and announcement of successful SRAEC proposals, a "kick-off" meeting was held on June 15, 1982 at NASA Goddard Space Flight Center. The objective of this meeting was to enable the principal investigators in the SRAEC Project to learn what their new collegues in the project were planning to do in their various studies and begin the process of sharing information and ideas for synergistic benefit to the remote sensing science program. Collaboration among principal investigators was encouraged.

The next meeting of the SRAEC principal investigators was held January 5-7, 1983 at the University of Colorado in Boulder in two separate sessions as a part of the National Radio Science Meeting. The objectives for this gathering of the PIs was to provide NASA management with a review of early progress, to initiate the sharing of results between SRAEC investigators and to emphasize the importance of reporting the study results with the broader remote sensing scientific community.

The second meeting to report on the research results was conducted at Colorado State University in Fort Collins from January 9-11, 1984. This second annual meeting was conducted with a workshop format and to serve as a forum for sharing terminology and articulate the merging of visible, IR, and microwave theoretical and experimental techniques. Tutorial presentations were made by representatives of these remote sensing disciplines. Although time constraints did not allow a full development of the ideas, good progress was made in bridging

the communications gap between the groups, which has been apparent in the most recent meeting.

The Third Annual Meeting of the SRAEC principal investigators was held on the campus of the Massachusetts Institute of Technology in Cambridge, Massachusetts during January 29-31, 1985. Dr. Jin Kong of the Research Laboratory of Electronics at MIT hosted this meeting and arranged for local scientists Ken Hardy and Dave Staelin to address the PIs and stimulate their thinking.

The letter of invitation to the principal investigators and the meeting agenda are included in Appendix A. A list of the workshop participants, their affiliations and addresses is provided in Appendix B. And a telecommunications message to the meeting participants from Dr. Robert Murphy, Fundamental Remote Sensing Science Research Program Manager at NASA Headquarters, is included in Appendix C. Dr. Murphy was personally unable to attend the meeting due to other committments.

The current document is the product of the contributions made by the SRAEC Principal Investigators, all of whom were present, at this annual workshop (Figure 1). This SRAEC annual status report is intended to 1) document responses to some of the questions addressed during the workshop concerning the progress, accomplishments and future directions of the project (Section II.A) and 2) to provide a concise summary of the justification, goals and objectives, and results of the individual SRAEC investigations (Section II.B), including an updated listing of the publications resulting from this research (Section II.C).

Figure 1. SRAEC principal investigators at the Third Annual Workshop on the campus of MIT on January 30, 1985. The PIs are (front row, left to right) Drs. Badhwar, Smith, Diner, Gerstl, Fung, Kahle; (second row) Ulaby, Strahler, Pearce, Paris, Conel, Moore, Kong; (third row) Irons, Norman, Fraser, Lang, Vanderbilt; (fourth row) Kimes.

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II. SRAEC PROJECT RESEARCH RESULTS

II.A. PROGRESS AND ACCOMPLISHMENTS

By the time of the Third Annual SRAEC Principal Investigator's Meeting the SRAEC Project was beginning its fourth year and most of the investigators had either completed or were nearing completion of their third year of research. It therefore seemed an appropriate time to look back on what had been done, what progress had been made toward addressing the "research issues" that had been identified at the inception of the program, and what recommendation could be made now concerning the future directions of the program.

A time for discussing the progress and accomplishments of the project was reserved on the agenda for the last day of the workshop to allow everyone to be updated on the progress of each of the investigations. Drs. Fawwaz Ulaby and Jim Smith accepted the responsibility for chairing these sessions and summarizing the results.

Four questions were presented to the participants in the workshop; three of which dealt with the success of the project and one which considered a topic of considerable interest to most of the scientists concerning the potential establishing a centralized facility for artificial plant canopy experiments. After some general discussion, each of the participants was asked to individually prepare a written response to four questions. The four questions are given below, and the summarized, selected responses are given on the following pages of this section.

In his cover letter (Feb. 20, 1985) reporting on the responses, Dr. Ulaby summarized by stating, "...the SRAEC program

is regarded by its members as 'one of the most successful programs NASA has ever run'." The principal investigator responses that follow contain numerous suggestions and varied opinions regarding future directions.

QUESTION NO. 1

Excluding your own contributions, what are the three most significant technical advances or developments that were accomplished under the SRAEC Project?

The responses to this question have been categorized according to:

(a) General Contributions
(b) Specific Contrib.--Optical Region
(c) Specific Contrib.--Microwave Region

QUESTION NO. 2

What accomplishments have been made in the SRAEC Project relative to the goals defined in its inception document? Suggest changes in direction, approach, or administration.

These responses have been grouped by:

(a) Accomplishments Relative to Goals
(b) Suggested Changes in Direction

QUESTION NO. 3

Are there "gaps" in the program? Should new areas be added? Should there be deletions?

QUESTION NO. 4

What are your views regarding the creation of a "National Canopy Facility"?

QUESTION #1

Excluding your own contributions, identify the three most significant technical advances or developments that were accomplished under the SRAEC Program.

The answers may be grouped into two classes: (a) general statements that address the overall technical direction of the program, and (b) specific statements relating to either the Optical or the Microwave portions of the program.

(a) General Contributions

"Remote sensing represents, in essence, an inverse problem. The characteristics of radiation fields are used to deduce surface properties. The two basic keys to the success of this are fundamental understanding of (1) the interactive properties of the target (the surface) and (2) the influence (if any) of the propagation medium.

Efforts towards canopy modeling which have resulted in basic models for BRDF's and/or backscatter cross sections are therefore a very important component to our progress in attacking this inverse problem."

"Create a nucleus of experts and expertise."

"The program has helped to bring together investigators from both the optical and microwave areas. As a result, both group's knowledge has been strengthened by techniques used in the other area. Examples are: the optical people were using transport theory--now the microwave investigators are using it also. The microwave researchers were more aware of the coherence effects and the non-uniform angular radiation properties of leaves and surfaces. The optical researchers are now measuring the BRDF of leaves and surfaces. In addition, the concentration

by the whole group on characterization of individual scatterers and the architecture of the canopy has led to an increased understanding of the relationships between measurements and biophysical parameters."

"I and other optical modellers are moving toward better understanding of the microwave problem. We all are working toward wavelength independent solutions to the scattering/absorbing problem."

"Interdisciplinary interaction among various groups: optical and microwave, atmospheric and surface researchers; experimentalists and theoreticians with investigators who develop inversion algorithms."

"Developing a better understanding of the interaction of radiant energy with surfaces, canopies, and atmosphere. Such knowledge enables development of better models and inversion algorithms."

"The bringing together of multiple disciplines has been useful in getting the optical surface people to think about atmospheric problems and microwave contributions, and vice versa. This has led to greater sophistication in scene characterizations."

"Smith's phase function work helps build an important bridge between optical, microwave and atmospheric work."

"I do think that a very important result was getting these diverse PI's together and exposing them to each other's work. I think that the communication links that were formed and the sharing of common

problems concealed in the different terminologies of the subdisciplines was most helpful and will pay benefits for a long time to come."

"To an outsider just joining this group, there appears to be too heavy an emphasis on a few areas (modeling of broadband electromagnetic radiation interaction with a few vegetative canopy types and measuring of some) to the exclusion of many other problems. I see little spectral work, no soils studies, no geology, no forestry, no mixing-model studies, no hydrology.... There are fundamental science problems in these areas, involving "SRAEC". Maybe nobody proposed to study them. Maybe announcement of opportunity needs to be more broadly written and distributed.

The work that has been and is being done by this program appears to be excellent and important."

"The development of a variety of computational tools for addressing the multidimensional terrain media problem, principally canopies."

"The beginnings of a solid, unified, attack on combined theoretical modeling of microwave/optical interactions."

"Establishment of the communications channel among scientists in optics and in microwave field. A fruitful and stimulating exchange is being developed."

"The potential unification of the theoretical frame work, which makes use of common mathematical approaches such as the radiative transfer theory."

(b) Specific Contributions--Optical Region

"I am impressed with progress being made in the visible-IR area in inversion to determine actual relevant plant canopy properties from data. I found Strahler's success with a simple model particularly striking."

"Established common theoretical basis for systematic evaluation of land remote sensing issues, i.e., radiative transfer, BRDF, phase functions, cross-sections, etc. Combined surface/atmosphere descriptions."

"Identified new and important sensitivities of electromagnetic radiation (emitted or reflected from land surfaces) to intrinsic surface features, e.g., spatial heterogeneities and non-Lambertian angular signatures."

"Identified angular reflection features that seem invariant to atmospheric effects."

"Tremendous progress has been made in testing,-evaluating and then improving canopy reflectance models in a systematic way. And with a clear confidence in these models, key biophysical parameters have been extracted. The 'Holy Grail' of remote sensing, the solution of the so-called 'signature extension' problem has been shown to exist and the role of canopy models in providing an understanding of this solution is clearly identified."

"The complete atmospheric-canopy problem has been studied by transport methods. Investigators have made initial attempts at obtaining boundary conditions for this model. Atmospheric correction methods of an elementary form has been proposed."

"The developments in atmospheric modeling coupled to the canopy reflectance models and measurements has ameliorated doubts regarding capabilities to observe canopy BDRF's through the atmosphere. Therefore, satellite remote sensing remains a viable tool for botanical, land-surface climatology, and habitability types of research.

"Sound practical approaches to atmospheric correction of digital image remote sensing data were discussed by Fraser and Dines (i.e., deblurring). The applied remote sensing community has been in desperate need for such an approach. I believe this development is immediately applicable."

"The fact that the canopy reflectance models are demonstratbly invertible is most encouraging. The continuing development of these models is probably the largest accomplishment of the SRAEC program.

"The most significant technical advance is that the effect of specularly reflected light is now being included in canopy models."

"The atmosphere/canopy is being treated as one problem rather than two. Phase functions pecific to each are being included."

"I believe that all of the research being done in the space program is addressing the goals of the inception document. The approaches of these studies are appropriate. The individual researchers have developed a strong theoretical background which provides a sound basis for exploring extraction techniques of desired canopy characteristics. These 'designs' of canopy characteristics are varied for many similar problems inside and outside of NASA as we have discussed. I believe

this is the area which will give the SRAEC program a great deal of publicity and future support."

"Significant advances appear to have been made in both measurement and characterization of BDRF's of a number of complex surface types."

"The potential merge of the vegetation canopy study and the atmospheric science, providing a complete framework for the study of the complete earth environment including earth terrain and atmosphere."

"The recognition at optical wavelengths, that besdies ectral signature, there are other observables which distinguish di. rent crop canopies, i.e., angular reflectance signature, temporal greenness profile, or scene textural analysis.

"The recognition that the information content of previous generation remote sensors (e.g., Landsat) is limited due to the restriction of nadir viewing. It appears that most interesting or useful effects appear at view angles greater than 45 degrees. A redirection of thinking to consider high off-nadir angles, taking into account the advantages as well as technical problems associated with such an approach, is a significant step.

"Time dependency of canopy reflectances seems to be a reliable crop identifier.

"Jim Smith improved his canopy phase function."

"Angular patterns of reflectance is understood only qualitatively (bowl-shape, hot-spot, "invariant valley), but not quantitatively. An artificial canopy with the possibility to set LAI, leaf, sizes, etc, may give us the hint to quantitative expressions."

"Unscrambling pixels affected by the adjacency effect."

"Identifying distinctive features for remote sensing (hot spot, persistent valley, specular reflections in visible IR, branch structure and the like for millimeter waves.

"Canopy reflectance models for inhomogeneous canopies."

"More detailed models of canopy BRDF that consider leaf and soil BRDF, partial cover and specular reflection."

"Calculating phase functions for canopy so general RTE code can be used to obtain BRDF predictions. Need to do better work relating this phase function to actual canopy architecture."

"The combined radiative transfer modeling, in a much more realistic way, of the atmosphere/surface problem with remote sensing implications."

"The potential merge of the vegetation canopy study and the atmospheric science, providing a complete framework for the study of the complete earth environment including earth terrain and atmosphere."

(c) Specific Contributions--Microwave Region

"Improved theoretical descriptions that are beginning to take into account the actual geometries better."

"Measurements of dielectric constants for materials and frequencies not well handled in the past."

"By replacing stems with lossy dielectric rods and leaves with lossy dielectric discs, modeling techniques can be used to approximately reproduce observed experiments."

"Rough surface effects have been incorporated into models showing that surfaces can exhibit strong backscattering at nadir angles."

"Much better understanding of the dielectric properties of a single leaf through measurements."

"Much improved understanding of the relative contribution of the component parts of a canopy."

"Scattering models with much wider ranges of applicability have been developed."

"Ulaby's measurements fill a great need."

"Different contributions of different canopy elements to the returned and transmitted signals in the microwave region, assessment of importance of those elements for microwave remote sensing."

"Putting microwave sensing on a very firm mechanistic basis, especially in the work of Ulaby and Lang."

"Trend towards understandable and usable models for backscattering in the microwave region."

"Some basic measurements like dielectric properties of soil, leaves, stalks, etc."

"Microwave modelers considering leaf angle distributions and stems and branches."

QUESTION # 2

Evaluate the accomplishments of the SRAEC program relative to the goals defined in its inception document. Suggest changes in direction, approach, or administration.

(a) Accomplishments Relative to Goals

"As far as I know, little has been done under controlled conditions to solve the stress-response problem directly--yet this is one of the most important from an applications point of view. Ulaby has done a lot of work on seasonal variations, per se, as have the French and Dutch.

"Ulaby has made extensive measurements of soil dielectric as part of this and other programs. This is an accomplishment.

"Goal 4 ('overriding necessity to relate to biophys parm.') is attacked by theory and experiment and may find culmination in work perceived for artificial canopy."

"Perhaps the most important justification for NASA to support SRAEC is to develop a strong scientific basis for the remote sensing programs being developed for the 1990s. The entire radiation spectrum that has high transmission through the atmosphere will be utilized."

"Relative to the accomplishments stated above, SRAEC program has made very significant progress towards the fundamental approach to the remote sensing science in unifying researchers from different disciplines, from different electromagnetic spectrum, from different schools of thought, and from both theoretical and experimental expertise."

"The first years of the SRAEC program have led to advances in developing the tools needed to address the question outlined in the inception document. While some of the questions may have not yet been answered, we are in a significantly better position to address them now than we were three years ago. The flexibility of the program is a major plus, allowing researchers free freedom to pursue new ideas and not be rigidly held to their proposals."

"I think the SRAEC research program has pretty well followed the goals objectives set out for the program at its inception. The original document called for a very broad research program with many topics and needs listed. Although not all of these areas have been attacked, the main thrust has clearly been along the lines of the plan. It seems to be funding a good balance of theoretical work, measurement, and work that is a bit more application-oriented. Except for the usual NASA bureaucratic problems (funding delays, etc.), the program has been well administered. I don't think it really needs much change."

"Modelers should not start impacting the applied programs. A question like: 'what is the best CR model for a given vegetation?' I believe, should be addressed by the group."

"Program is proceeding toward stated goals at a rapid pace and I would not change the approach or administration and would let the direction continue to be defined by the original document."

"Much better than I would have thought. While individuals may come and go, I believe it is important to keep some collective memory. I believe administration by NASA has been exemplary. Overall, a first class group doing first class work under enlightened NASA enviornment fostering creativity and comraderie."

"Relative to the accomplishments stated above, SRAEC program has made very significant progress towards the fundamental approach to the remote sensing science in unifying researchers from different disciplines, from different electromagnetic spectrum, from different schools of thought, and from both theoretical and experimental experties."

(b) Suggested Changes in Direction

"Perhaps the more glaring gaps in the program are filled with the induction of geologists into the group. We need better coverage on the properties of rocks and soils. We need thermal band coverage. These are addressed to some extent with the recent program addition. On the other hand, we have not, as a group, looked at snow or ice. We have not looked at the sea although useful observations might be possible, especially for coastal waters.

"Little has been done to improve cross-polarized measurements. Use of circular reflectors of parabolic shape leads to significant cross polarization. Low-cross-polarization arrays or horns should be used in such measurements. Cross-polarized returns have significant potentials, as demonstrated years ago with the Westinghouse 35 GHz radar, and more recently with ERIM, CCRS and JPL radars."

"Nothing has been done in this program with regard to snow and ice dielectrics, although some other work relates to them. The problem is complex, and perhaps should be left to the Arctic and Air Force programs."

'I see no need for a change in direction."

"I agree with Dr. Smith's statement that the SRAEC program needs to extend applications of radiative transfer theory to other terrestrial media. I am biased towards the study of soils. Other media obviously include snow, ice, exposed rock, and even water bodies (e.g., the turbid waters of the Great Lakes)."

"Steps need to be taken to ensure the transfer of SRAEC accomplishments to applied remote sensors. In particular, these accomplishments are of immediate and great utility to those scientists planning retrospective and field observations for ISLSP."

"The greatest strength of the program is the heavy emphasis on development of better understanding of the canopy radiation field using modeling as an approach."

"As implemented, this emphasis has elevated determination of LAI, leaf angle distribution etc. (e.g., a very limited set of parameters) as an end objective. This is both good (we need to know them) but also bad (we must not lose sight of the goal to obtain information. The variables or parameters mean nothing by themselves. To be useful, they must be put in some context and they must be used with other information. The modeling efforts tend to neglect these aspects.

Thus, there is a need to better relate the modeling activities to basic botanical information."

"SRAEC investigations should commence on all subjects that are not now being done properly. Examples may be snow-ice, hydrology, wet lands, soil and shore erosion, etc.

"There were almost no intercomparisons between different models addressed to the same topic."

"Validation, verification and sensitivity analysis of existing models are still needed. This can be done by using numerica simulation in the case of rough soil surface and perform basic experiments on artificial canopy of known potentials in the case of vegetation layers."

"Extension of the existing models to heterogeneous media is being done but not yet completed."

"To relate electromagnetic parameters to the classical biophysical descriptions--much progress has been made over recent years both experimentally and from modelling viewpoint."

"Stronger links between experimental programs and theoretical work are still desirable. Should encourage joint efforts or proposals from theoreticians and experimentalists."

"Basic measurement should now be de-emphasized. Some modeling effort be directed to check models against observations already made."

"SRAEC program needs more research related to incoporating as many aspects of the soil-plant-atmosphere system as possible. We have emphasized radiation exchange, but numerous other processes are closely related to radiation exchange such as evapotranspiration and dry matter production and there should be some attempt to bridge this gap with as rigorous an approach as possible."

"Further developments are needed in relating classic biophysical descriptors to electromagnetic parameters (e.g., Biomass needs to be estimated as opposed to LAI and LAD). These needed developments, however, will likely follow from the current research direction."

"One gap is in not using the theoretical radiation capability assembled in SRAEC program to address problems of leaf BRDF as it depends on leaf structure - internal (cells, chloryplasts, air gaps, water, etc.) and external (epidermis, cuticle, surface irregularities, etc.)."

"Much more emphasis needs to be placed on the inverse problem both in terms of rigorous theoretical models and simple algorithms that can be used efficiently on millions of pixels. This universe problem needs to include the atmosphere in the near future."

"I think there were not enough model intercomparisons."

QUESTION # 3

Are there gaps in the program? Should new areas be added? Should there be deletions?

"It seems to me that a gap exists in tying the microwave and vis-IR response together. The ulitmate application is going to involve sensor combinations with combined use of vis-IR and microwave when vis-IR is possible, and use of microwave alone when clouds obscure the ground."

"If natural vegetation is the goal these days, it seems to me that we are not doing justice to some forms of natural vegetation. Specifically, I see almost no effort on grassland and sparse desert vegetation. Although other programs are addressing snow cover, sea ice, etc., at least some link to these would be appropriate. Moreover, urban areas are a part of the environment--a very big part in some places--yet nothing seems to be underway with regard to them except a tiny effort on our part to look at radar sources in wooden buildings."

"Another area that seems to be receiving too little emphasis is uncovered lithology. It is fine that it is starting in the thermal IR, but the visible and microwave regions are not being treated. We have done some work in the past that shows that one really can get lithologic signatures in the microwave, but the surface has barely been touched."

"Much work needs to be done for grasses and forest canopies in both canopy models and hope to extract key biophysical variables. A clear need to attack (or combine) canopy reflectance models with atmospheric models needs to be done, though a start has been made (Gerstal)."

"The important gap in the program is the lack of a systematic plan to verify individual models with carefully controlled experiments. The experiments should be made on both real and artificial canopies. All investigators should be notified of the experiment in advance and have the opportunity to have ground truth that might need to be measured."

"In the optical area, there is a need to have the individual scatterers in the canopy carefully modeled."

"Both in optics and microwaves, the inversion of present models should be carried forth. Since this is our ultimate goal, the groups should start to address this portion of the work more seriously."

"There are gaps in two areas. There is a crying need for research to provide means to obtain the input parameters needed for use in canopy radiation models. That is, we need better instruments to measure/estimate LAI, LAD, etc in a timely manner. At present we are quite capable of collecting enormous amounts of spectral reflectance data on numerous fields but only limited amounts of supporting data on only a few fields. Thus we need a machine to measure the canopy geometry. We need support for collection of a limited amount of scanner polarization data, preferably polarized AIS type data, in support of my area and other modellers. Without these data we will not be able to address these questions.

(1) How is light, scattered and polarized by a plan canopy, transmitted through a disturbing atmosphere over a large area. (2) Is polarization data another independent source of information about the scene--providing another 'channel' of information for discriminating species and assessing the condition of the plant canopy on the ground."

"An error analysis needs to be made for the entire remote sensing system to determine the amount of research that is required for each component of the system. The system consists of the surface, canopy, atmosphere, sensor, processing the measurements, and finally inversions. If the accuracy of only one component of the system is only five percent, say, then it may be unnecessary to achieve much greater accuracy for any other component. Sensors should not be built at great expense with greater accuracy than is justified by the accuracy of the remaining components in the system."

"Lack of interaction between SRAEC investigators and meteorologists and climatologists."

"Only the thermal region is missing in the existent programs."

"The gaps in the program are related to the issues addressed in question 1, which are in fact the future directions that we should be concentrating on. It will be of fundamental importance to unify the optics and the microwave approaches, to include earth terrain media other than vegetation canopy, and extend the atmospheric study to include both the lower and the upper atmosphere. With such interdsiciplinary approaches, we should be able to establish credential in accountability and applicability to NASA goals such as the global habitability studies, and at the same time remain in the domain of fundamental research."

"Gaps: The thermal is an obvious gap that has been mentioned. Snow surfaces are not being addressed, and should. New work in soils and rock spectra are extending our knowledge of scene radiation to include phenomena beyond plant canopies. I think the program should continue to broaden in this way, but still keep its emphasis on fundamental research unknowns.

"There is now a critical need for more coherent involvement of measurement and modeling. The so-called "National Canopy Facility" is all manifestation."

"Inversion of models to obtain biophysical parameters from remotely sensed data."

"Considering the funds available and the number of people involved, the program is very balanced. The biggest gap I see is a strong research program on modeling thermal IR phenomena."

"Thermal IR studies of the surface, including multi-angular studies as well as investigation of IR sounding to characterize the atmosphere."

"The addition of someone in the lidar field would be useful, to get the optical passive and active communities talking to each other, as well as to give the laser community a better sense of the type of atmospheric information that is needed in order to correct images for atmospheric effects."

"The gaps in the program are related to the issues addressed in Question 1, which are in fact the future directions that we should be concentrated on. It will be of fundamental importance to unify the optics and the microwave approaches, to include earth terrain media other than vegetation canopy, and extend the atmospheric study to include both the lower and the upper atmosphere. With such interdisciplinary approaches, we should be able to establish credential in accountability and applicability to NASA goals such as the global inhability studies, and at the same time remain in the domain of fundamental research."

QUESTION # 4

What are your views regarding the creation of a National Canopy Facility?

"Considering the effort required to establish a chosen and various LAI and LAD for a canopy of credible size (number of "leaves", etc), it would seem to me that it might be better to devote effort to devising rapid, comprehensive, and accurate techniques for measurement of the geometrical leaf descriptions than to constructing a hardware model of large scale.

"The use of models in experiments is important in many investigations, but it is also important that individual experimenters use simple models at their own sites to answer simple questions quickly. The whole job cannot be done effectively with one or two massive models used by everyone. Perhaps these are desirable for comparison purposes and for classes of experiments where simple models will not do."

"Geometric scaling should be possible for answering most modeling problems. This means that the models can be much smaller than the real world, which makes them easier to use in some ways. For microwaves this means that a higher frequency must be used than the frequency that would be used with the real thing, but this is not hard to do. I see no real problems with doing this scaling in the optical-IR regime, and it should allow the models to be much more tractable. Moreover, for a dense canopy. there is no need to model the entire thickness, since the radiation will not penetrate beyond a certain depth anyhow!"

"I recommend a very inexpensive, simple canopy at first to see if tnis idea is really worth putting the time and money into."

"Absolutely necessary because (1) angular distribution (besides time variation) of canopy reflectance seems to be a valuable crop identifier and (2) angular pattern of reflectance is understood only qualitatively (bowl-shape, hot-spot, invariant valley), but not quantitatively. An artificial canopy with the possibility to set LAI, LAD leas sizes, etc may give us the hint to quantitative expressions."

"I believe there is a strong need to establish a "controlled" facility for a variety of representative media (not just canopies). Some tests would be very simple/some complex. Considerable thought should go into such a program-wide resource--it is important to do it right and assure that sufficient resources be allocated for a sustained effort--not a "one-shot" deal. I am reasonably confident that funds from other agencies could be identified to match NASA funds.

I am quite concerned that such a facility be established and maintained by a group/groups that already have existing measurement expertise in microwave/optical regions. I think a combined facility could be beneficial. I need to think through some steps/ways to get things going. I have some significant requirements for the optical case."

"I believe there is well-defined value, over all programmatic interests, in the NCF: models are not verified in full as being invertible for enough distinctive canopy features, we need to understand "hidden variables" or hidden assumptions about canopy structure (especially pair correlations of leaves or other scattering structures).

"I think that construction of a National Canopy Facility will be a total waste of scarce resources. For homogeneous and uniform canopies, CR models exist which represent the CR quite accurately (within the measurement accuracy). For complex canopies, the models are not as good but a complex artificial canopy will be hard to make and will itself introduce unwanted artifacts.

I support the concept of an individual P.I. proposing an artificial canopy experiment as part of his/her proposal."

"I favor the idea of an artificial canopy being explored. However, there must be at least a promise of learning something from this that we do not already know. Also, I would hope that it is not so conceived and constructed that it becomes an end in itselt without contributing to the real vegetation remote sensing problem.

I think that a significant effort should be funded to explore designs for such a facility using expertise from a broad cross section of the biological and remote sensing communities. This would involve materials, questions, logistic questions, radar vs. optical, and outlines of some reasonable projects that it would be used for.

After this one year or more of study, the question should be posed well enough to be evaluated in a peer review system. Whether this artificial canopy has naything to offer will depend strongly on the design and we need to know specifics that are generated from a broader cross section of potential users."

"I don't think large amounts of money should be spent on making an artificial canopy closely resembling plants when one could spend 69¢ on a seed packet and grow the real thing! To me, the utility of an artificial canopy would be to convincingly demonstrate that canopy properties can be recovered uniquely for relatively simple (but non-trival) geometries, because if that can't be done, then I don't see how crop situations can be inverted. Thus, there is no pressing need for the artifical canopy to resembly plants other than in some gross way. If such a simple canopy can't be constructed for under, say, $10,000, we're getting into dollar amounts that might be better spent elsewhere, especially in this time of budget limitations."

II.B. PRINCIPAL INVESTIGATOR SUMMARY REPORTS

Each of the principal investigators was requested (see Appendix A) to bring to the Third Annual SRAEC Principal Investigator's Meeting a succinct summary research report that provided information on the 1) justification, goals and objectives; 2) experimental approach; and 3) study results, with up to three key figures to illustrate their findings. In addition, a separate listing of publications and presentations on their research was also requested (see Section II.C.)

The remainder of this section contains the individual investigator's summary research reports in the following order:

Smith	Reflectance Modeling (p.37)
Norman	Bidirectional Reflectance Modeling of Non-Homogeneous Plant Canopies (p.45)
Kimes	Understanding the Radiant Scattering Behavior of Vegetated Scenes (p.53)
Vanderbilt	Measurement and Modeling of the Optical Scattering Properties of Crop Canopies (p.59)
Strahler	Geometric-Optical Modeling of a Conifer Forest Canopy (p.66)
Badhwar	Crop Characteristic Research: Growth and Reflectance Analysis (p.71)
Conel	Ground Reflectance Measurements from Thematic Mapper Data (p.78)
Kahle	Thermal Infrared Geometric Remote Sensing Research (Co-I, Bartholomew) (p.85)
Diner	Atmospheric and Scene Complexity Effects on Surface Bidirectional Reflectance (p.92)

Fraser	Atmospheric Effect on Remote Sensing of the Earth's Surface (p.99)
Pearce	The Characterization of Surface Variegation Effects on Remote Sensing (p.106)
Gerstl	Multidimensional Modeling of Atmospheric Effects and Surface Heterogeneities on Remote Sensing (p.113)
Fung	Scattering Models and Basic Experiments in the Microwave Regime (Co-I, Blanchard) (p.119)
Kong	Remote Sensing of Earth Terrain (p.125)
Lang	Discrete Random Media Techniques for Microwave Modeling of Vegetated Terrain (p.129)
Ulaby	Microwave Dielectric and Propagation Properties of Vegetation Canopies (p.135)
Moore	Determination of Backscattering Sources in Various Targets (p.141)
Paris	Active Micowave Properties of Vegetation Canopies (p.147)

N86-13795

REFLECTANCE MODELING

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PROJECT OBJECTIVES

The overall goal of our work has been to develop a set of computational tools and media abstractions for the terrain bidirectional reflectance problem. The modeling of soil and vegetation surfaces has been emphasized with a gradual increase in the complexity of the media geometries treated. Pragmatic problems involved in the combined modeling of soil, vegetation, and atmospheric effects have been of interest and one of our objectives has been to describe the canopy reflectance problem in a classical radiative transfer sense permitting easier inclusion of our work by other workers in the radiative transfer field.

APPROACH

The application of radiative transfer theory to soil and vegetation media requires an abstraction of the scattering and absorbing properties of the medium in terms of biogeophysical attributes, a specification of the geometrical boundary of the medium, and a mathematical solution technique to the radiative transfer equations. We have abstracted our media to consist of a collection of discrete scatterers, e.g. leaf or soil facets, with individual diffuse and specular optical properties. Bulk properties of the media are usually derived from suitable averaging over the statistical distribution of the individual elements within the medium. For simple plane parallel media geometries, we are using classical solutions to the radiative transfer equations, e.g. the discrete ordinates/ finite difference method of Chandrasekhar, the Adding method of Van de Hulst, or the two stream method of Kaufman. For complex geometries with irregular rough surfaces, we are employing Monte Carlo techniques.

RESEARCH FINDINGS

We will briefly summarize three areas which have been addressed since the last SRAEC annual meeting. These are orthogonal expansion of our phase functions in terms of total scattering angle and example use with standard radiative transfer code, e.g. Kaufman's two stream approximation; our Monte Carlo reflectance modeling for complex soil surfaces which now include Fresnel facets; and our current work in modeling complex vegetation surfaces.

Orthogonal Expansion and Utilization of Canopy Phase Functions

We have previously described our calculational technique for averaging over leaf angle distributions and leaf optical properties to estimate the canopy scattering diagram as a function of the global incident and exitant

angles. The phase functions we presented were given in terms of incident angles, μ,ϕ and exitant angles, μ',ϕ'. As Ross has indicated, it appears that canopy phase functions, unlike some of the more symmetrical atmospheric cases, may not necessarily be explicitly formulated in terms of only a total scattering angle, Θ. We have spent some time pondering this circumstance. Recently, we have adapted an approach outlined by Liou for ice crystals whereby "average" phase functions can be computed. The procedure essentially averages over ranges of μ,ϕ and μ',ϕ' which yield the same total scattering angle, Θ, i.e.

$$\cos\Theta = \mu\,\mu' + (1-\mu)^{1/2}\,(1-\mu')^{1/2}\cos(\phi-\phi') \qquad (1)$$

We term the resulting scattering diagrams, "stylized" phase functions. We do not believe the results are strictly correct in the fine details, because of both fundamental reasons and numerical problems. However, as Van de Hulst has indicated, for many calculations the fine details may not be all that important. Theoretically, the phase functions are much more tractable and be expanded, in Legendre polynomials, for example, as follows:

$$P(\cos\Theta) = u_0 + u_1 P_1(\cos\Theta) + u_2 P_2(\cos\Theta) + \ldots \qquad (2)$$

and, thence, into a variety of useful forms. The table below shows an example calculation for a spherical leaf angle distribution for visible and near infrared wavelengths. The phase function, and, hence, expansion coefficients vary with the vegetation optical properties.

	λ = 0.55 μ m	λ = 0.65 μ m	λ = 0.80 μ m
u_0	1.009	1.018	1.018
u_1	0.057	-0.238	-0.271
u_2	0.174	0.180	0.183
u_3	-0.022	-0.053	-0.051
u_4	0.021	0.028	0.033
u_5	-0.001	-0.021	-0.024
u_6	0.021	0.022	0.026

NOTE: u_0 should be 1.0; some measure of the numerical precision of the calculations is indicated by the deviations from this value above.

Such expansions can be easily incorporated into standard radiative transfer code. We have used the above values in Kaufman's published modified two stream method—the program code was obtained from the Atmospheric Science Department at Colorado State University. Figure 1 is a plot of the (spline - smoothed) stylized phase functions at the three wavelengths above.

Monte Carlo Soil Reflectance Modeling

At last year's SRAEC some preliminary results from a Monte Carlo model for the reflectance of a rough soil were presented. The thrust of our work in this area over the past year has been to extend the usefulness of this model to surfaces having non-Lambertian elemental reflectance properties. In particular, we were concerned with the effect of a distribution of Fresnel facets superimposed on macroscopic surface irregularities . The reflectance properties of an element of area of surface covered by these facets was determined theoretically, and then this reflectance function was substituted for the original Lambertian one in the Monte Carlo model.

In the substitution of reflectance functions into the Monte Carlo model it was desirable to allow the most general forms possible. For this reason two alternatives were investigated: the approximation of the reflectance functions in terms of spherical harmonics, and the use of a lookup table generated from the value of the reflectance functions at discrete angles. After some preliminary testing it appears that the former approach is slightly better when the reflectance function in question is simple, however for more complex functions, and in particular for the functions arising from distributions of Fresnel facets, the lookup table approach is the only reasonable one.

Thus far, we have only considered the case when the Fresnel facets have a uniform distribution of inclination angles. An example of the sort of results obtained for a surface with a simple cosine undulation is given in Fig. 2a. In this case light was incident on the surface at a zenith angle of 45 degrees and an azimuth perpendicular to the direction of the rows. The results are given by plotting contours of equal reflectance factor on a polar plot in which distance from the center indicates the zenith view angle, and the azimuth of the view corresponds directly to that on the plot. Figure 2b shows the bidirectional reflectance distribution function for the same surface possessing purely Lambertian elemental scattering properties.

Reflectance From Complex Vegetation Surfaces

After reviewing the bidirectional reflectance distribution modeling work for vegetation media currently underway in the SRAEC fundamental research effort, we concluded that it would be useful to attack the problem of reflectance from a rough surface vegetation layer from a multiple scattering, radiative transfer perspective. The approach we chose is an outgrowth of Norman's work and complements Strahler's geometric optics approach utilizing stylized structures for tree crowns. Basically, we are adapting a Monte Carlo code by utilizing probability of gap expressions which take into account the varying optical path length through vegetation layers as a function of canopy density, macro-structure and look angle. Geometrical routines are used to compute required parameters from a canopy height profile. In practice we employ Fourier series expansion of canopy height profiles. Later we may examine statistical structures inherent in the data via power spectra analysis and formulate appropriate models. These ideas are partially generated from some thermal modeling work we are performing over a forested site at Oak Ridge National Laboratory and we are

capitalizing on the canopy structure data available for this site.

This work is in preliminary stages, but briefly our approach follows:

1. An adapted version of our Monte Carlo vegetation reflectance model will be used to handle the multiple scattering calculations.

2. Probability of gap expressions are computed for photon interactions by considering both micro (i.e. leaf angle distributions) and macro (canopy height profile) structure. Specifically,

$$P_o(\Theta) = \exp - LAI*g(\Theta)*D(\Theta) \ /h \qquad (3)$$

where $g(\Theta)$ is the mean canopy projection in direction Θ, LAI is leaf area index, and $D(\Theta)$ is the geometric path length from the bottom of a canopy later to the top profile in direction Θ, and h is the canopy layer thickness.

3. Appropriate geometrical computational routines have been developed to calculate $D(\Theta)$ for an arbitrary canopy height profile. We have applied these routines to sample data transects from the Oak Ridge Site. In practice, the canopy height profile data are first "detrended" using least squares regression, and the the power spectra computed for the detrended data in order to develop Fourier series representations for the calculation routines. Figure 3 shows a sample detrended height profile, and schematically illustrates the varying path lengths through this canopy layer as a function of look angle. Multiple voids in the canopy are correctly handled.

SIGNIFICANCE AND NEXT MAJOR STEP

The main significance in our work is an increased understanding, expressed via a variety of computational procedures, of terrain bidirectional reflectance properties. To our knowledge, there were no macro soil reflectance models for complex surfaces incorporating the complete multiple scattering solution and accounting for shadowing effects. Our calculation, treatment, and utilization of canopy phase functions also appears to be somewhat novel, although we have built upon the efforts of earlier workers. Extensions could be made to our work to include, for example, the incorporation of media subelement models to account for physiological or polarization properties.

In the eight months remaining of our third year of funding the final step in our research focus will be to complete a tractable treatment of complex vegetation surfaces amendable to our Monte Carlo canopy reflectance modeling techniques. In addition, we will more gracefully complete several loose ends in our completed work including the generation of orthogonal expansions of our canopy phase functions and the utilization of the models developed under this study to illustrate soil/vegetation/atmospheric effects in such applications as AVHRR-derived vegetation index calculations.

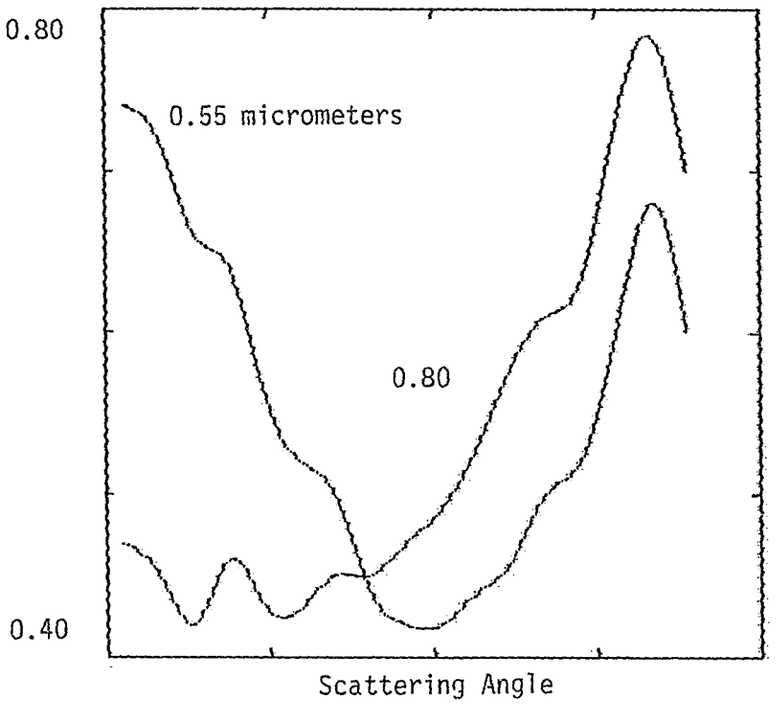

Figure 1. Stylized Canopy Phase Functions as a Function of Scattering Angle for wavelengths of 0.55 and 0.80 micrometers. (Normalization is incomplete)

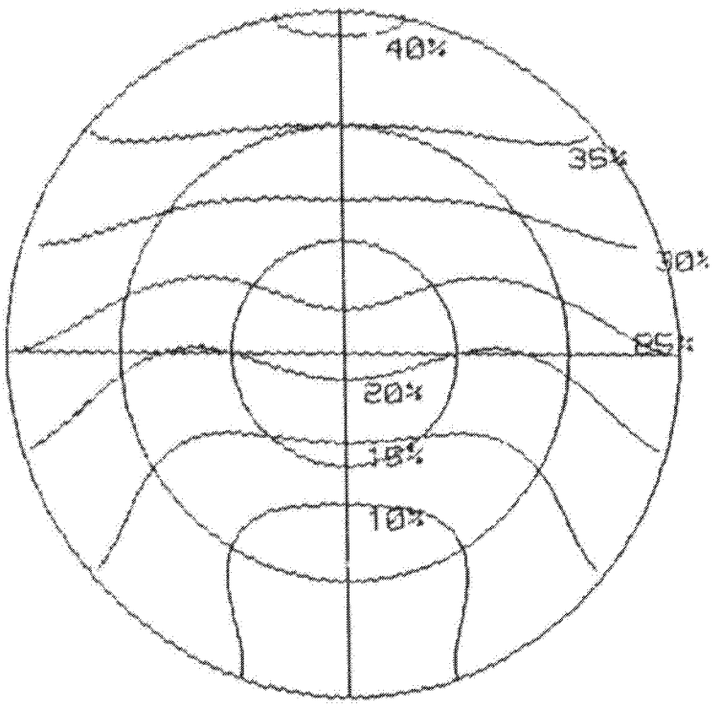

Figure 2a. Polar plot of bidirectional reflectance distribution function from a row soil surface with partially specularly reflecting Fresnel facets. Sun is at 45 degrees with azimuth perpendicular to rows. Elemental reflectance is 28%.

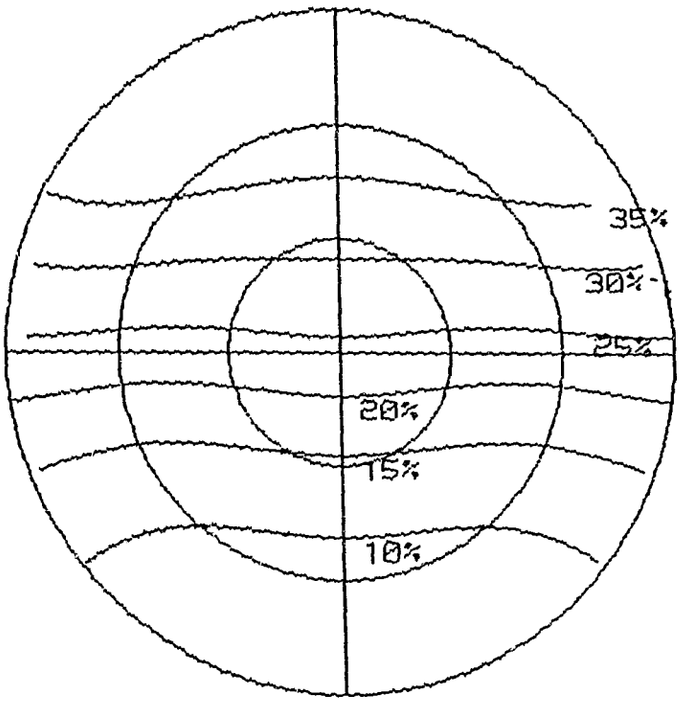

Figure 2b. Polar plot of bidirectional reflectance distribution function from a row soil surface with strictly Lambertian elemental reflectance properties.

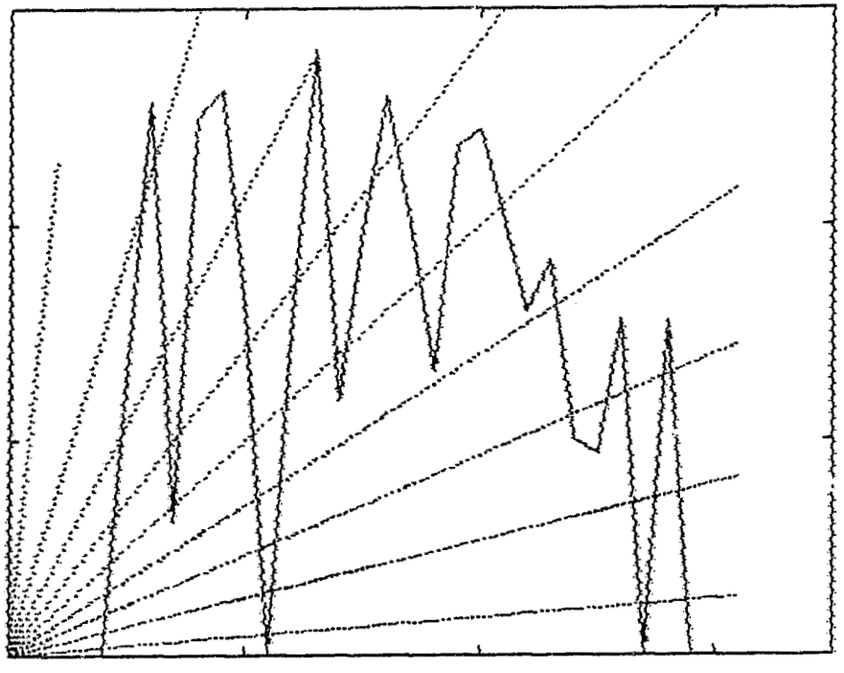

Figure 3. Detrended height profile for forest transect and probability of gap calculation for path length as a function of look angle.

N86-13796

BIDIRECTIONAL REFLECTANCE MODELING OF NON-HOMOGENEOUS PLANT CANOPIES

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Objective

The objective of this research is to develop a 3-dimensional radiative transfer model for predicting the bidirectional reflectance distribution function (BRDF) for heterogeneous vegetation canopies. The model (named BIGAR) considers the angular distribution of leaves, leaf area index, the location and size of individual subcanopies such as widely spaced rows or trees, spectral and directional properties of leaves, multiple scattering, solar position and sky condition, and characteristics of the soil. The model relates canopy biophysical attributes to down-looking radiation measurements for nadir and off-nadir viewing angles. Therefore inversion of this model, which is difficult but practical, should provide surface biophysical properties from radiation measurements for nearly any kind of vegetation pattern; a fundamental goal of remote sensing. Such a model also will help to evaluate atmospheric limitations to satellite remote sensing by providing a good surface boundary condition for many different kinds of canopies. Further this model can relate estimates of nadir reflectance, which is approximated by most satellites, to hemispherical reflectance, which is necessary in the energy budget of vegetated surfaces.

Technical Approach

The approach to this research requires development of the mathematical equations and computer coding of the heterogeneous-canopy model, better characterization of leaf and soil properties which are a serious limitation at the present time, and finally comparison of model predictions with field measurements that are obtained from other investigators. The Bidirectional General Array Model (BIGAR) is based on the concept that heterogeneous canopies can be described by a combination of many subcanopies, which contain all the foliage, and these subcanopy envelopes can be characterized by ellipsoids of various sizes and shapes. The foliage within an ellipsoid may be randomly positioned or non-randomly positioned. Estimates of multiple scattering are obtained by transforming each point of interest in a particular ellipsoidal canopy to an equivalent one-dimensional canopy and solving the radiative transfer equations for this simple case. The BRDF for individual leaves has been measured so that appropriate leaf properties can be used in the model. The BRDF for several soils has been measured and modeled with a simple block-modeling approach to provide a reasonable lower boundary condition for the canopy model. Field measurements of corn and soybean canopy BRDFs are compared with model predictions.

Research Results

The results of this study are three fold: 1) A simple soil BRDF model tested with measurements, 2) laboratory measurements of leaf BRDFs for live corn and soybean plants grown in the greenhouse and the field, and 3) the development and validation of a 3-dimensional canopy BRDF model of heterogeneous vegetation that combines soil, leaf, and canopy-architectural information.

The simple soil BRDF model approximates a soil aggregate by a single rectangular block placed on a fixed lot area with a fixed orientation relative to the sun azimuth. The relative reflectance factor in any view direction is computed from projections of block faces and the shadow of the block on the horizontal. Fig. 1 contains a comparison of model results with measurements in the solar waveband over a rough surface that was recently plowed from sod with furrows approximately 15 cm deep. The RMS difference between the surfaces is 2.2% in reflectance. The simple-black-model predictions fit measurements from smooth (0.5-1 cm gravel) and medium rough (2 to 5 cm clods from multiple tillages) even better with 1% RMS differences in reflectance.

Leaf BRDF measurements were made at 3 source incidence angles (20, 45, 70) and about 50 view angles for intact corn and soybean leaves attached to their respective plants. The distribution visible and near-infrared, reflectance and transmittance factors is shown in Fig. 2 for a 45 degree source incidence angle. The leaf hemispherical reflectance, which is essential to all models of vegetation radiation exchange, was calculated from the integral of the BRDF (Table 1). Clearly normal incidence valves which currently are being used in other models may not be appropriate since mean leaf-sun angles for most canopies are between 45 and 60 degrees and not near normal incidence.

The 3-dimensional bidirectional reflectance general array model (BIGAR) predictions have been compared to measurements on corn and soybeans that were obtained from the Laboratory for Applications to Remote Sensing (LARS), Purdue, University, West Lafayette, Indiana as part of the AGRISTARS program. An example of how ellipsoids are used to represent a young corn canopy is shown in Fig 3 and a comparison of measured and modeled results is in Fig. 4. In general the model predictions agree very well with measurements considering that soil BRDF measurements cannot be made for the same site as the vegetation BRDF measurements.

A simple 3-term empirical equation has been derived to fit measured and modeled, soil and canopy BRDFs over a wide range of wavelengths. The RMS reflectance difference between the 3-term empirical equation and modeled or measured distributions (including view zenith angles from 0 to 60 degrees) is about 0.2% in the visible and 2% in the near infrared for soybeans and several soils; a remarkably good fit.

Significance of Results

Significant research results from this study impact on vegetation remote sensing in three ways: 1) relation of soil BRDF to roughness and sun angle, 2) interactions between soil BRDF and canopy reflectance properties that lead to confounding the discrimination of sparse vegetation using angle-of-view observations, and 3) interpretation of leaf BRDF measurements to provide more suitable leaf spectral properties for models of vegetation radiative transfer.

The very simple block model, which has beem verified with field measurements, relates the soil BRDF to roughness. Unfortunately the roughness is a relative roughness and thus not the same kind of "roughness" used by soil physicists, Thus a disked field and a gravel lot can have similar relative roughnesses (ratio of size to spacing) and BRDFs but represent very different roughnesses to the soil physicist.

The BRDF of sparse vegetation is not as different from soil as is desirable for discrimination based on view angle observations. However the structure of sparse canopies may be distinguishable from each other or soil backgrounds with zenith view angels of 60^{o}. Unfortunately this is not possible from satellites. In addition we now understand how a BRDF is different for a soil below a canopy than a soil in the open even though their physical characteristics are identical. The 3-term empirical equation fits soil and vegetation BRDFs so well that it may greatly simplify extraction of canopy properties from off-nadir observations for natural surfaces so that use of such data may become practical. Perhaps it may even reduce the number of off-nadir angles needed for obtaining canopy properties from satellite observations.

During this study we have measured leaf BRDFs for corn and soybean; a rather formidable task that few have attempted. From this work we have learned that models based on normal-incidence integrating sphere leaf spectral properties, and to date nearly all leaf spectral property data is for normal incidence, are using underestimates of leaf reflectance and overestimates of transmittance. Using the more appropriate leaf spectral properties may change canopy reflectance by 5 to 15% of the reflectance value. The improved estimates of leaf spectral properties will also improve estimates of canopy water use and photosynthesis. In fact the reduced water use of an isogenic line of dense pubescence (dense hairs) soybeans could only be explained by the leaf BRDF and not normal incidence integrating sphere measurements.

Future Work

Future research should emphasize the inversion of 3-dimensional vegetation-soil bidirectional reflectance factor models and develop simpler inversion algorithms from exercising these complex models. Both angular (view direction) and wavelength information should be combined in the inversion process to extract the maximum amount of information; perhaps inverting the distribution of normalized-difference with view angle may hold promise. The logical extension of this 3-D model is to include more complex canopoy architecture such as conifer trees, and also extend the wavelength band to the thermal.

Table 1. Hemispherical reflectance and transmittance of corn and soybean calculated by integrating the results of leaf BRDF measurements.

Crop	Incidence Angle	Visible Refl (%)	Visible Trans (%)	NIR Refl (%)	NIR Trans (%)
Corn	0	7.7	3.9	-	-
	20	9.1	4.2	34.6	39.3
	45	9.3	3.4	33.0	35.4
	70	14.2	3.9	45.2	45.0
Soybean	0	8.3	4.9	-	-
	20	9.3	4.3	41.7	30.9
	45	9.6	3.7	44.9	33.2
	70	15.3	3.1	51.6	32.0

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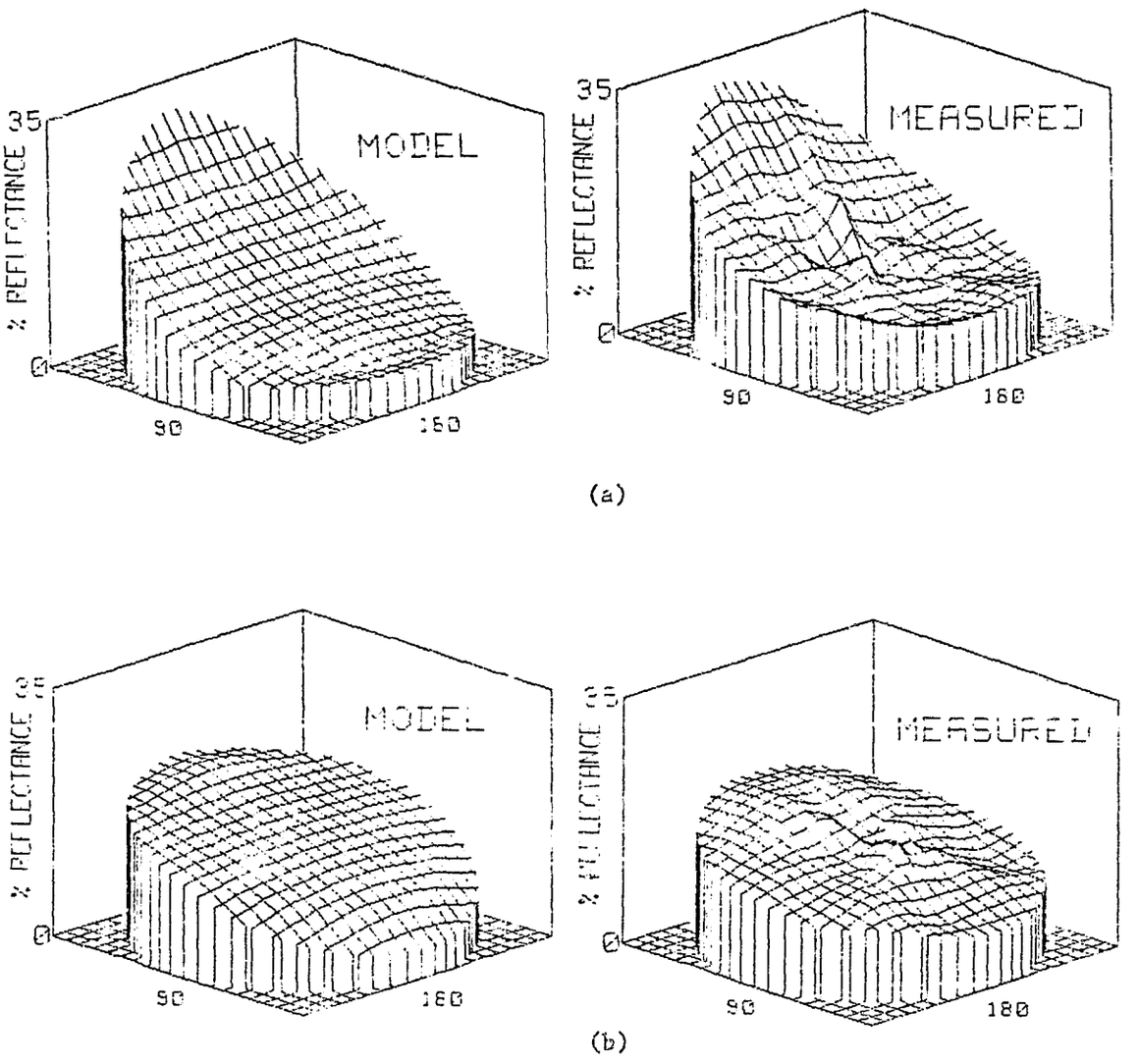

Fig. 1. Soil BRDF predicted from simple model(H=0.4, L=0.85 W=0.1, =0.67) and measured for a rough plowed soil with 15 cm furrows and clods for a solar zenith angle of (a) 63° and (b) 28°. The RMS difference between measured and modeled for (a) is 2.2% and for (b) is 1.1% in reflectance units. Maximum zenith view angle is 60° (outer rim), center is nadir and sun azimuth is 0°.

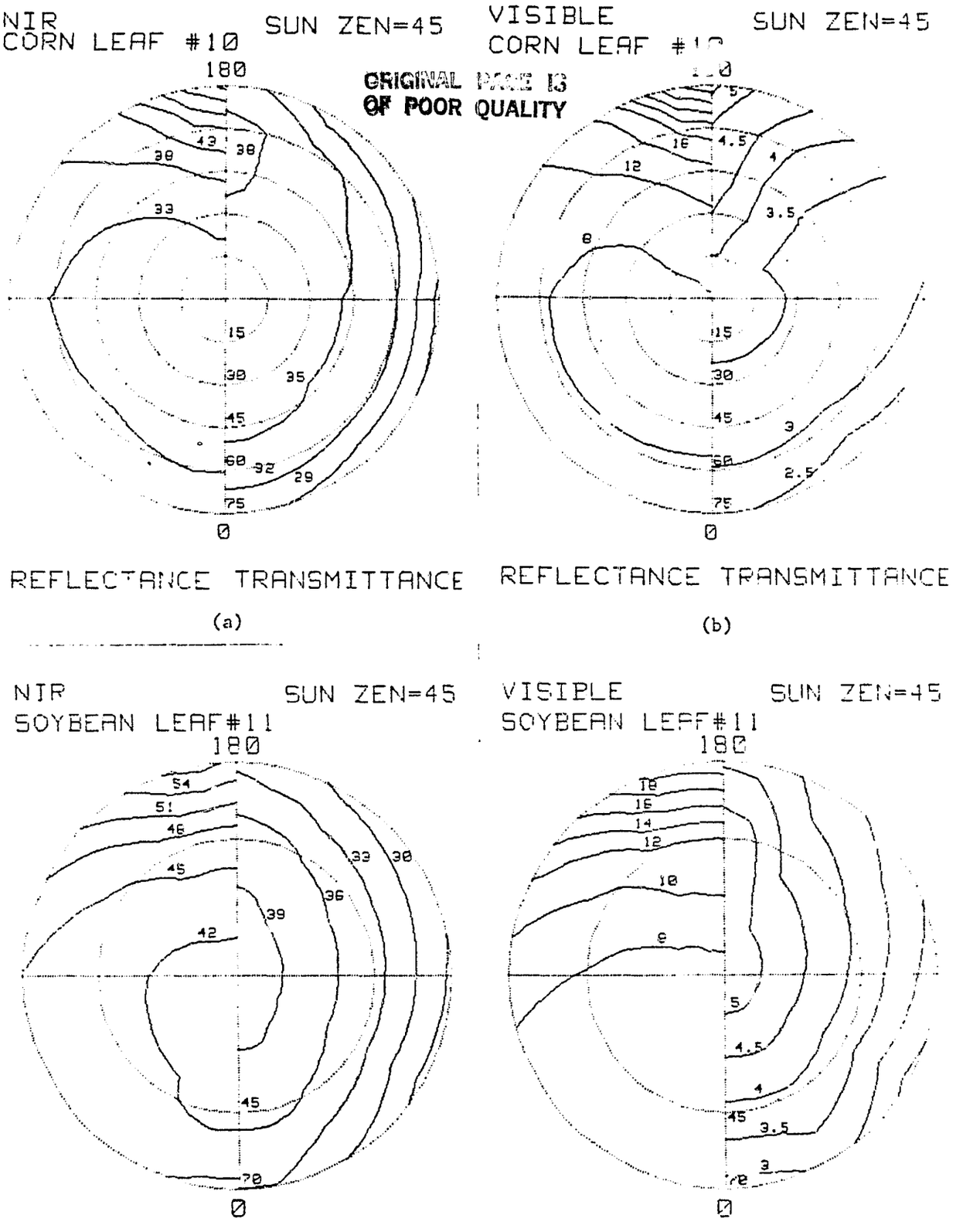

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Fig. 2. Leaf BRDF and bidirectional transmittance distribution function at a source incidence angle of 45° and azimugh of 0° for (a) corn at near infrared wavelengths, (b) corn at visible wavelengths, (c) soybean at near infrared wavelengths, and (d) soybean at visible wavelengths.

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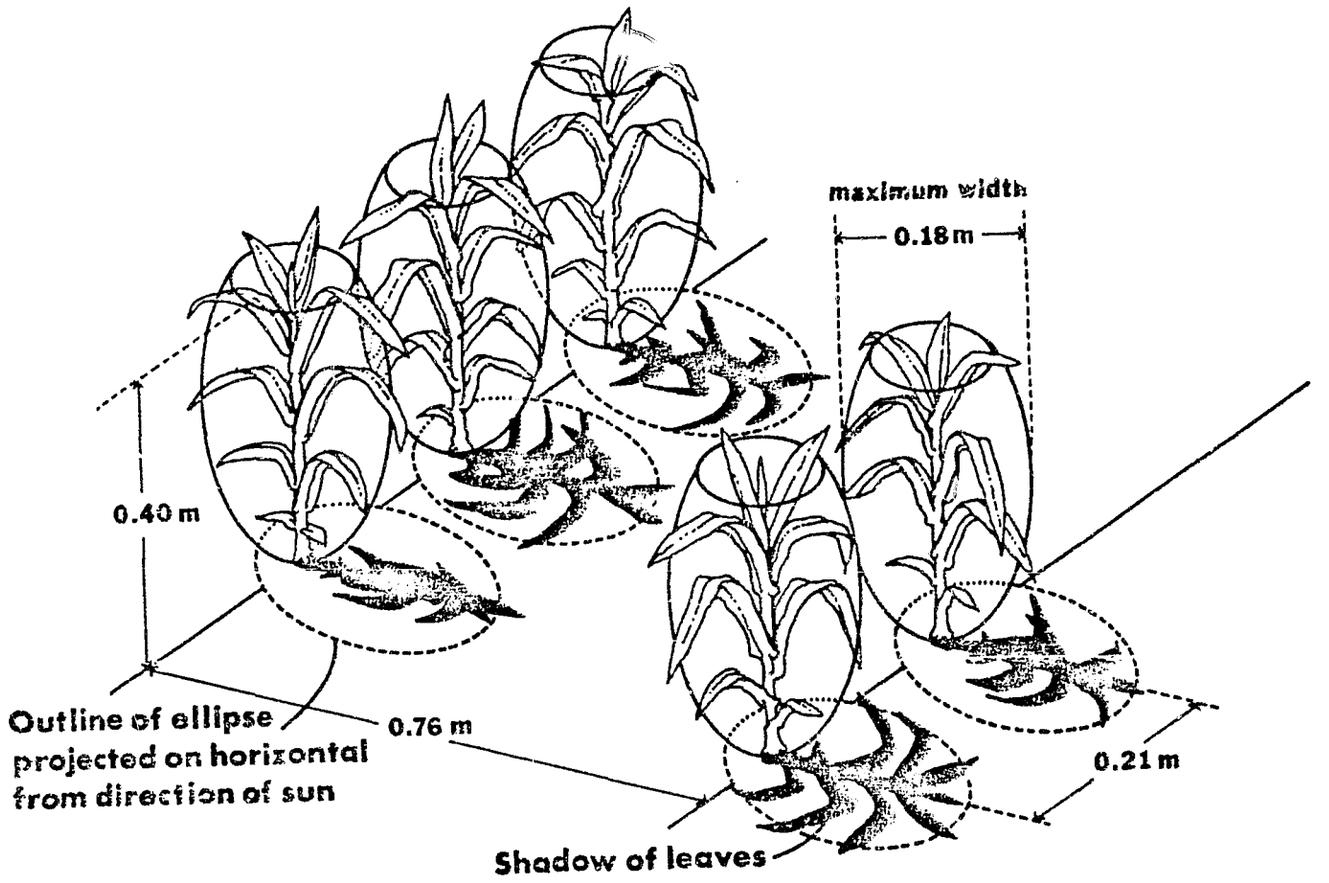

Fig. 3. Sketch of a corn canopy with LAI= 0.4 including the ellipsoids used to approximate the canopy envelope.

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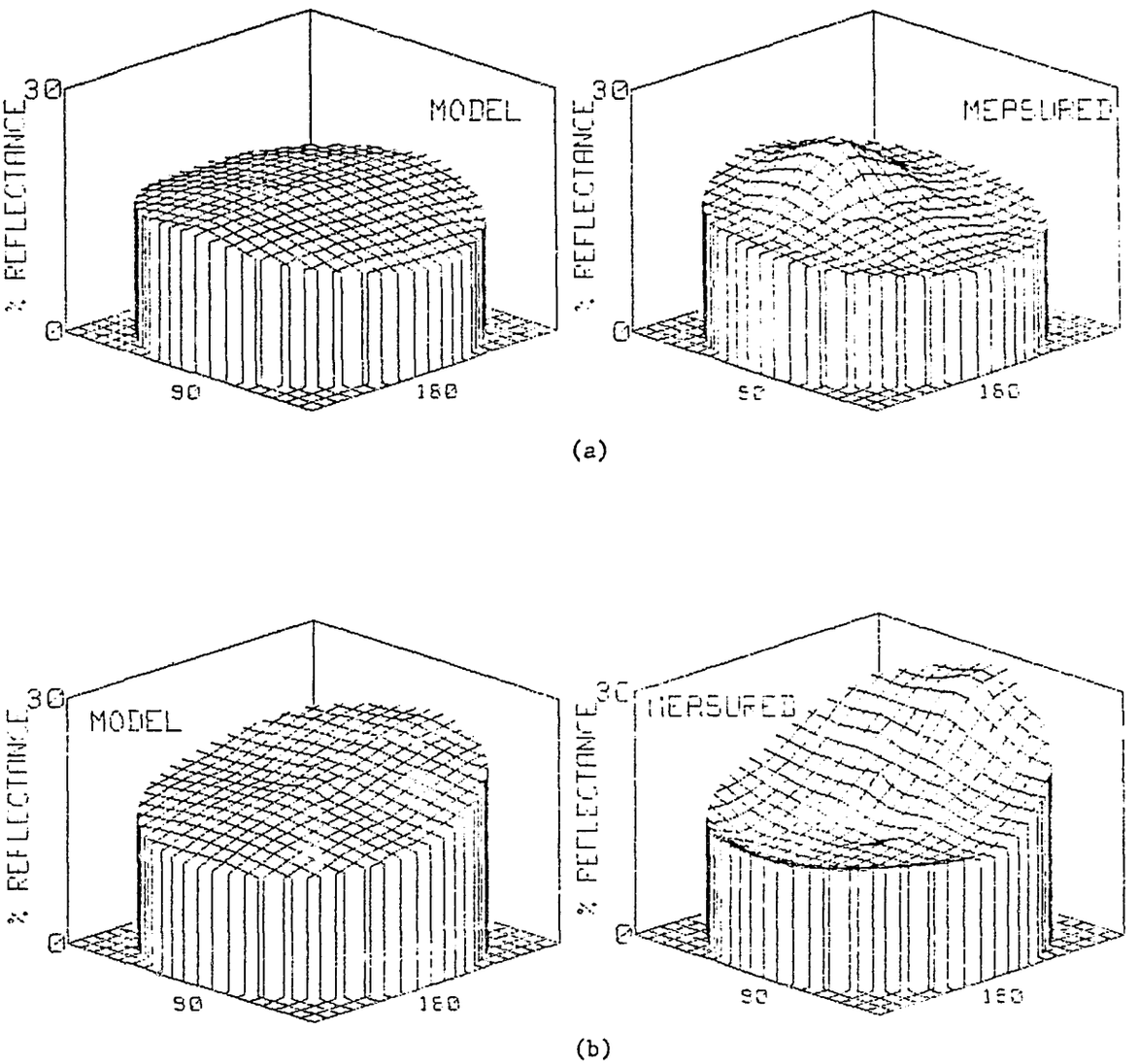

Fig. 4. Comparison of measurements and model predictions for a corn canopy of LAI = 0.4 having north-south rows. (a) solar azimuth = 7°, solar zenith = 18°, (b) solar azimuth= 276°, solar zenith = 47°. South is 0°. Maximum view zenith angle is 60° (outer rim) and nadir view is at the center.

N86-13797

UNDERSTANDING THE RADIANT SCATTERING BEHAVIOR OF VEGETATED SCENES

Daniel S. Kimes
NASA/GSFC

Fundamental knowledge of the physics of the scattering behavior of vegetation as gained in this study is important. This growing body of knowledge will ultimately serve the remote sensing and earth science community in many ways. For example, it will provide (1) insight and guidance in developing new extraction techniques of canopy characteristics, (2) a basis for better interpretation of off-nadir satellite and aircraft data, (3) a basis for defining specifications of future earth observing sensor systems, and (4) a basis for defining important aspects of physical and biological processes of the plant system. Such fundamental knowledge is very important to the long term advancement of remote sensing and earth science programs. The overall objective of the three-year study is to improve our fundamental understanding of the dynamics of directional scattering properties of vegetation canopies through analysis of field data and model simulation data. The specific objectives were to (1) collect directional reflectance data covering the entire exitance hemisphere for several common vegetation canopies with various geometric structure (both homogeneous and row crop structures), (2) develop a scene radiation model with a general mathematical framework which will treat 3-D variability in heterogeneous scenes and account for 3-D radiant interactions within the scene, (3) conduct validations of the model on collected data sets, and (4) test and expand proposed physical scattering mechanisms involved in reflectance distribution dynamics by analzying both field and modeling data.

Using a Mark III 3-band radiometer, directional reflectance distributions spanning the entire exitance hemisphere were measured of natural vegetation canopies ranging from bare soils to complete with 100% ground cover. NOAA 7/8 AVHRR bands 1 (0.58-0.68 μm) and 2 (0.73-1.1 μm) were used in data collection. The cover types reported were corn, soybeans, grass lawn, orchard grass, alfalfa, cotton row crops, pine forests, hardwood forests, plowed fields, annual grassland, steppe grassland, hard wheat, salt plain, and irrigated wheat. All measurements were taken from the ground except the forest canopy measurements which were taken from a helicopter. Leaf area index, leaf angle orientation distributions, probability of gap functions, leaf reflectance and transmittance, and soil reflectance were measured on some of the canopies.

A three-dimensional radiative transfer model was developed (Fig. 1) and is unique in that it predicts (1) the directional spectral reflectance factors as a function of the sensor's azimuth and zenith angles and the sensor's position above the canopy, (2) the spectral absorption as a function of location within the scene, and (3) the directional spectral radiance as a function of the sensor's location within the scene. It is one of two existing models with such general three-dimensional capabilities. This 3-D model was expanded to include the anisotropic scattering properties of leaves as a function of the leaf orientation distribution in both the zenith and azimuth angle modes. The model was applied to complete vegetation canopies of various leaf orientations--erectrophile (mostly erect leaves),

planophile (mostly horizontal leaves), spherical (equal probability of all leaf orientations), and heliotropic (sun tracking leaves). The model was also validated and analyzed for agricultural crop canopies, natural grassland canopies and forest canopies. The model was used to explore the radiative transfers that take place in these various scenes.

The analysis of the field data and model simulations yielded significant information on the radiant scattering behavior of the vegetation canopies. The results showed unique reflectance distributions ranging from bare soil to complete vegetation canopies for agricultural crops and natural grasslands. Physical mechanisms causing these trends were proposed based on scattering properties of soil and vegetation. Soil exhibited a strong backscattering peak toward the sun (Fig. 2). Complete vegetation exhibited a "bowl" distribution with the minimum reflectance near nadir (Fig. 3). Sparse vegetation canopies showed shifting of the minimum reflectance off of nadir in the forward scattering direction because both the scattering properties of the vegetation and soil were being observed. In addition, sparse canopies exhibited the strong backscatter peak of the soil at relatively small solar zenith angles. The largest variations in reflectance with changing view angle occurred at large solar zenith angles for canopies with very low vegetation covers. As vegetation densities increased and the solar zenith angle decreased, reflectance variations decreased. The dynamics of the directional reflectance distributions were analyzed and physical principles responsible for the observed dynamics were proposed. Past studies have demonstrated that the normalized difference transformation [AVHRR (Band 2 - Band 1)/(Band 1 + Band 2)] is useful in monitoring green vegetation biomass. A difficulty in utilizing AVHRR data that scans out to 56° is that the signal for any particular target can change significantly with various view angles. It was demonstrated that this transformation generally decreased the directional variation of the signal. However, there were exceptions. For each remote sensing application the user should be aware of these variations for the specific cover types being studied, solar zenith angle and scanning direction of the sensor with respect to the solar azimuth. It was found that complete canopies with different leaf orientation distributions (erectophile, spherical, planophile, and heliotropic) had unique reflectance distribution characteristics. The dynamics of these distributions were physically explained by directional scattering effects of two mechanisms. The first mechanism causes the characteristics "bowl" shape of complete canopies that is--increasing reflectance with increasing off-nadir view angle for azimuth directions. It is caused by shadowing gradients and view projection gradients within the canopy. The second mechanism is the primary directional scattering of the leaves (phase function) due to leaf orientation, source direction, and leaf transmittance and reflectance values. The combination of these two mechanisms in the various canopies are responsible for the dynamics of the overall shape of the directional reflectance distributions.

The results showed that the scattering behavior of relatively dense forest canopies is very similar to the scattering behavior of agricultural crops and natural grasslands. Only in more sparse forest canopies with significant spacing between the tree crowns (or clumps of tree crowns) does the scattering behavior deviate from homogeneous agricultural and natural grassland canopies. This clumping of vegetation material has two effects on the radiant transfers within the canopy. (A) It increases the probability

of gap to the understory and/or soil layers which increases the influence of the scattering properties of these lower layers and (B) It increases dark shadows within the scene causing increased backscatter and decreased forward scatter to occur relative to the homogeneous case. Both phenomenon tend to increase backscatter relative to forward scatter. For typical forest canopies, the peak backscatter reflectance can be increased as much as 30% relative to an equivalent homogeneous canopy due to phenomenon A and 35% due to phenomenon B. The combined effect of phenomenon A and B can cause typical increases of 65% or higher. It is hypothesized that these phenomenon are especially important in sparse conifer forests such as the boreal forest which account for 50% of the world's forest area.

The understanding of the radiant scattering behavior of vegetated scenes gained in this studied can lead to intelligent techniques for extracting canopy parameters from remotely sensed data. For example, estimating the hemispherical reflectance (albedo) of terrestrial surfaces is of great importance in studying biospheric and atmospheric processes. It is proposed that satellite borne instruments represent the only practical means of obtaining global estimates of surface albedo data at reasonable time resolution; the problem being how to relate the nadir or directional reflectance observations from such sensors to the integrated hemispherical reflectance. This study investigated (1) the relationships between directional reflectances and hemispherical reflectance and (2) the effect of solar zenith angle and cover type on these relationships. The results showed that errors in inferring hemispherical reflectance from nadir reflectance can be as high as 45% for all cover types and solar zenith angles. By choosing a solar zenith angle between 30°-40° the same error is reduced to less than 20% in both bands. For both bands a view angle of 60° off-nadir and $\pm$90° from the solar azimuth reduces this error to less than 11% for all sun angles and cover types. A technique using two specific view angles reduces this error to less than 6% for both bands and for all sun angles and cover types. These techniques may yield considerable dividends in terms of more reliable estimation of hemispherical reflectance of natural surfaces.

These fundamental research efforts have improved our physical understanding of radiant scattering in vegetation canopies. This has been accomplished through the analysis of both model simulation data and field directional reflectance data in the visible and near infrared wavelengths. The directional scattering behavior of vegetation has been described and explained for various solar zenith angles, and various canopies with different densities, leaf orientation distributions, and optical properties. The work has been in response to providing an intelligent basis for defining specifications of earth observing sensor systems and for inferring important aspects of physical and biological processes of the plant system.

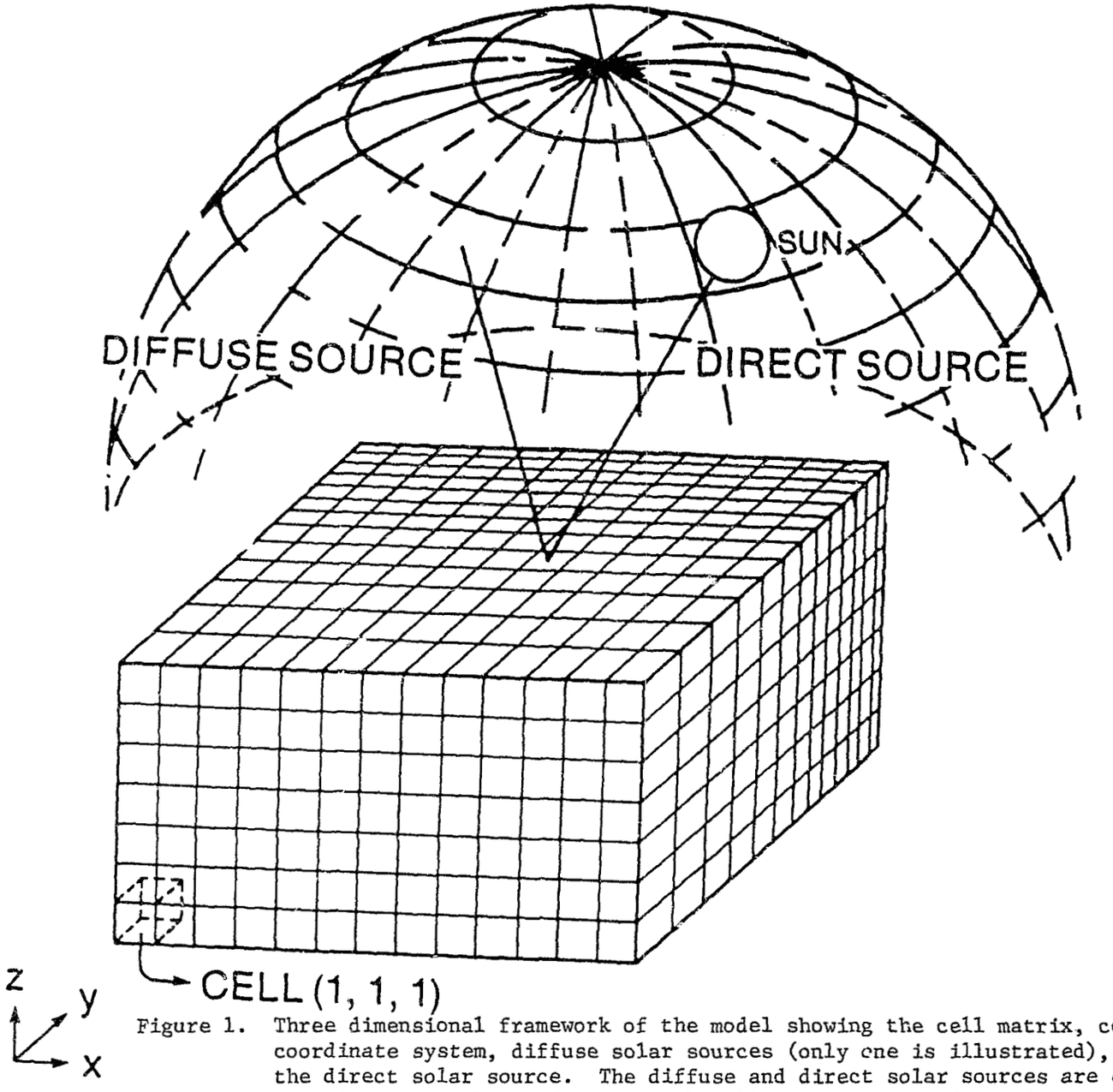

Figure 1. Three dimensional framework of the model showing the cell matrix, cell coordinate system, diffuse solar sources (only one is illustrated), and the direct solar source. The diffuse and direct solar sources are extended down to the surface of each cell on the top surface of the cell matrix. Any 3-D scene can be represented by "filling" the cells with various materials with different densities and scattering properties.

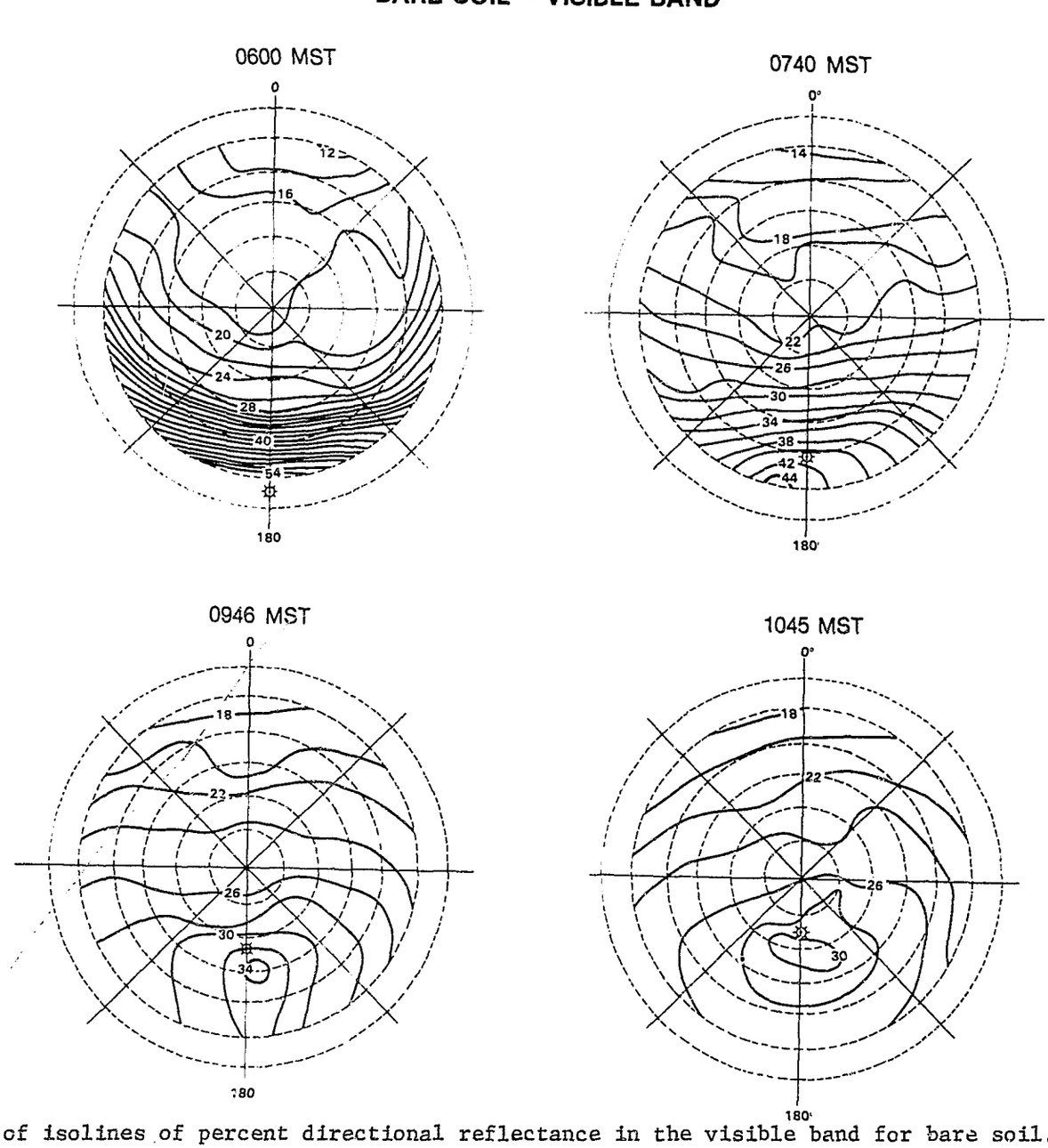

Figure 2. Polar plots of isolines of percent directional reflectance in the visible band for bare soil. The distance from the origin represents the off-nadir view angle of the sensor and the azimuth angle represents the sensor's azimuth. The solar azimuth is always 180°. A sensor with 0° azimuth looks into the sun, the dashed lines represent 15° increments of off-nadir view angle (0°-90°). The solar position is shown as a small starred circle on each plot.

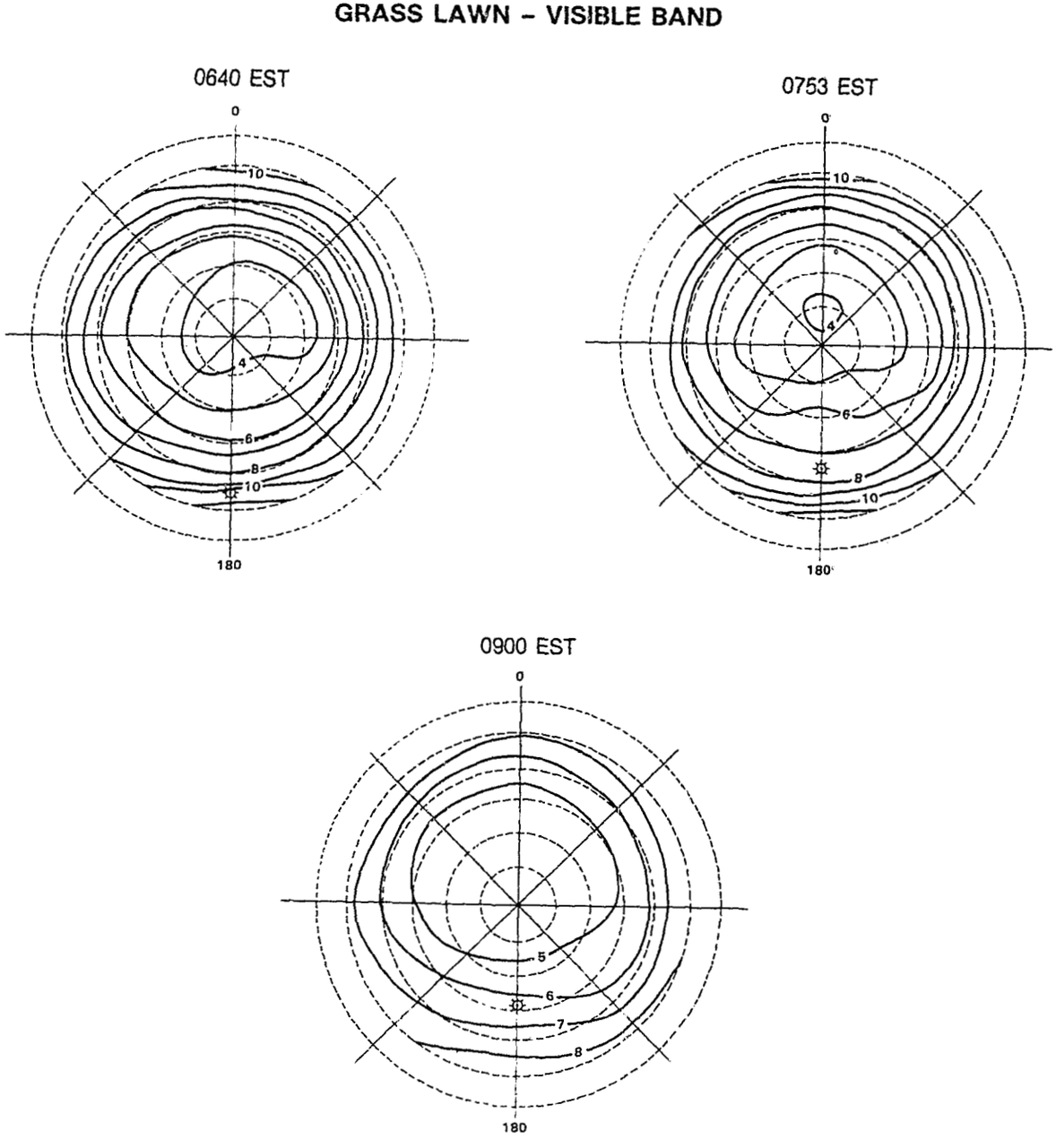

Figure 3. Polar plots of isolines of percent directional reflectance in the visible band for a grass lawn. Symbols follow Figure 2.

N86-13798

MEASUREMENT AND MODELING OF THE OPTICAL SCATTERING PROPERTIES OF CROP CANOPIES

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I. Justification of Research

The amount of sunlight specularly reflected by such plants as sunflower, corn, sorghum, wheat, and grass is often so large that canopies of these plants appear white instead of green when viewed obliquely toward the sun.

Specular reflections from the shiny leaves of plants originate at the interface between air and the cuticle wax layer. Unlike the diffuse portion of the light reflected by a leaf, the specular portion of the reflected light is reflected at the first surface it encounters; it never enters the leaf. From the Fresnel equations of optics, the light reflected by such a shiny surface is polarized. The polarized portion of the reflectance may be species dependent and related potentially to the physiological status and development stage of the canopy - to such botanical variables as leaf age and plant water status and temperature regime.

All of this suggests that remotely sensed polarization measurements of a plant canopy will contain information about the leaf surfaces -- information independent of that already identified in the light reflected from the interior of the leaves measured in the various spectral regions. The information is independent because the polarized portion of the reflected light does not enter the leaf to interact with cell pigments, walls or water.

Polarization measurements, although certainly a potential source of useful information about the earth, have never been acquired routinely by satellite-borne imaging sensors as part of earth observation research. The reason is simple; the research area is virgin. Hard evidence in the form of physically-based theories supported by actual data has only recently begun to demonstrate the actual -- not merely potential -- information in such data. More evidence is needed before a dedicated satellite-borne sensor system would be justifiable.

II. Research Objectives

The overall objective is to investigate the potential information in the polarization data of both single leaves and plant canopies. This research is measuring, analyzing, and mathematically modeling the specular, polarized, and diffuse light scattering properties of several plant canopies and their component parts (leaves) as a function of view angle and illumination angle. The potential of these bidirectional radiation properties for ground cover discrimination and condition assessment is being evaluated.

III. Approach

The research approach has proceeded in both empirical and theoretical directions. Measurements performed at our laboratory demonstrate the relationship between polarization data and various optical and botanical properties of both pieces of foliage and plant canopies. The data provide a basis for gaining fundamental understanding of how light is scattered and

polarized by a plant canopy. A mathematical model has been developed for predicting the specular and polarized light scattering properties of plant canopies. By exercising the model we have developed better understanding of the potential information in polarization data.

The empirical part of the approach has involved demonstrating our new technique for determining specular, polarized, and diffuse components of the reflectance factor of both leaves and plant canopies. Applying this new technique to our field measurements, we have determined the specularly scattered and polarized light from a plant canopy as a function of view and illumination directions. To these reflectance data, we have appended the ancillary data of the plant canopies for use by ourselves and other investigators developing and testing light-canopy interaction models, such as our specular reflection/polarization model.

A polarization photometer was developed to investigate the potential information in the mean and standard deviation of the polarized/diffuse components of the reflectance factor of leaves measured individually in vivo at six wavelengths at the Brewster angle. Measurements were made (1) in a survey of plant species and varieties representing crops, forests, "weeds," and horticulture, including as factors (when appropriate) leaf pigmentation, development stage, position of leaf on plant, and position of instrument on leaf, (2) of a corn canopy as a function of its moisture stress, and (3) of a greenhouse-grown wheat innoculated with wheat rust.

IV. Results

We present three results of our research, (1) a theoretical model of the specular-polarized light scattered by a plant canopy, (2) data demonstrating a linear relationship between the relative water content of a leaf and its non-polarized reflectance, and (3) data demonstrating the importance of the variable, angle of incidence, in explaining the polarization of light scattered by plant canopies.

A. Theoretical Model

A model was developed for predicting the amount of light specularly reflected and linearly polarized by the leaves of such plant canopies as wheat, corn, and sorghum. The model is based upon the morphological and phenological characteristics of the canopy and upon the Fresnel equations which describe the light reflection process at an optically smooth boundary separating two dielectrics.

The theory demonstrates that, potentially, measurements of the linearly polarized light from a plant canopy may be used as an additional feature discrimination. Examination of the model suggest that, potentially, satellite polarization measurements may be used to monitor plant development stage, leaf water content, leaf area index, hail damage, and certain plant diseases. The modeling results show that the angles of the polarization analyzer on a radiometer or satellite-borne sensor measuring a ground scene may be predicted from the view and illumination directions.

Applicability of the model of the canopy specular reflectance should extend to many species because leaves - which specularly reflect sunlight - are ubiquitous, unconfined by geography or climate.

The modeling results, Fig. 1, show that for the predictions from the model the single variable, angle of incidence (on the leaf) of the sunlight specularly reflected to the sensor, explains much of the variation, as a function of view direction (both zenith and azimuth), for a plant canopy with a uniform

(spherical) leaf angle probability density function. For example, at any specific angle of incidence, 30 degrees, for example, the predicted R_Q, Fig. 1, changes little for zenith view angles less than about 40 degrees, only changing significantly for angles approaching 90 degrees. The physical interpretation of this prediction, Fig. 1, is that at any given angle of incidence there are more specularly reflecting leaves in the field of view of the sensor at large zenith view angles near 90 degrees than near 0 degrees. For example, for the sun on the horizon in the east and for view directions varying from 0 degrees up to the horizon to the north, the angle of incidence will be constant at 45 degrees in all these view directions; however, the number of specularly reflecting leaves in the field of view of the sensor will be least at 0 degrees zenith view angle and greatest at the horizon.

B. Leaf Moisture vs. Reflectance

To investigate if relationships exist between reflectance and moisture-stressed vegetation, measurements were acquired on the leaves of corn, grown in a field under moisture-stressed conditions. (A physiological disturbance of a plant usually results in an increase of reflectance in the visible portion of the spectrum.) Twenty-four hours prior to reflectance measurements, a portion of the field was flood irrigated. Leaves for reflectance measurements came from (a) this irrigated treatment, (b) the field-grown, stressed conditions, and (c) leaves excised from plants subjected to rapid desiccation. The water status of each individual leaf was quantified by measuring the relative water content of each leaf sampled for leaf reflectance measurements.

Fig. 2 depicts the reflectance in the red wavelength band (650 nm) as a function of relative water content (RWC). The results, Fig. 2a, show that when the RWC of these corn leaves i[illegible], the reflectance factor, R, tended to decrease. But within this range of relative water contents sampled (between 50% and 100%), the variaton in the reflectance factor is great - making the usefulness of the reflectance measurements for predicting the relative water content slight. Fig. 2b shows there is no relationship between the polarized component of the reflectance factor, R_Q, and relative water content.

But there is a relationship between the non-polarized component of the reflectance factor and relative water content, Fig. 2c, which increases linearly (R^2 = 0.77) with decreasing relative water content. This relationship appeared valid even for relative water contents greater than 80%, a moisture regime for which other investigators have found hemispherical leaf reflectance to be a poor estimator of relative water content. The non-polarized component of the reflectance factor thus appears to be a better predictor of relative water content than the reflectance factor.

C. Plant Canopy Angle of Incidence

In field experiments designed to provide comparisons between the model predictions and polarization data, we measured two plant canopies, each in a variety of view directions as the sun moved, providing illumination in a continuum of directions. More than 200 spectra were acquired on two wheat canopies in the boot (preheaded) and dough (headed) stages of development, and on each date in each of 33 view directions.

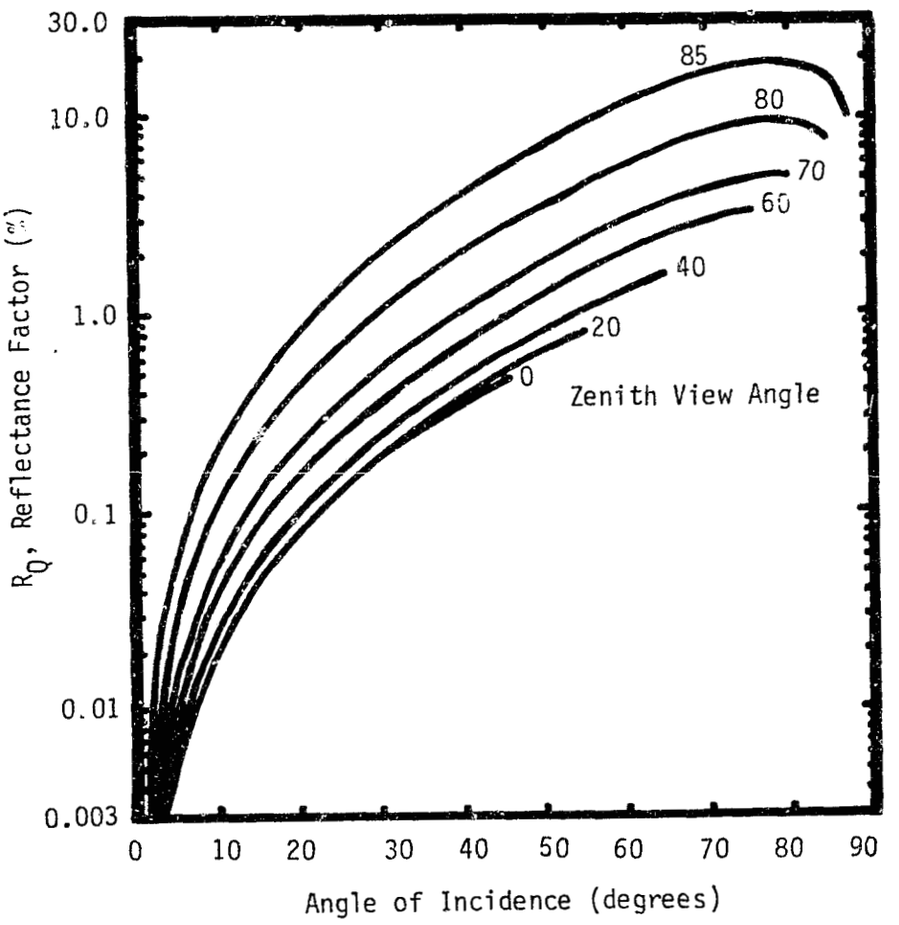
The degree of linear polarization (Fig. 3) at a wavelength of 0.66 um is plotted for 19 June and 17 July for four view zenith angles and angle of incidence, gamma. Regardless of zenith or azimuth view angles, the data points for June 19 fall within a narrow region defining an arc. On July 17 the scatter in the data is generally greater, although those data acquired at a view zenith angle of 60^o define a fishhook-shaped curve.

Fig. 3 shows that most of the variation on June 19 in linear polarization as function of the two variables, view zenith and view azimuth angles, is explained by the single variable, angle of incidence, a prediction of the specular/polarization model. The angle of incidence is computed knowing that a small area of shiny leaf must be uniquely directioned to specularly reflect sunlight to an observer. For the headed wheat of JUly 17, the angle of incidence explains the variation in the linear polarization at a zenith view angle of 60^{o} (albeit the arc-shaped relationship of June 19 is a fishhook on July 17) but less well at smaller zenith view angles. The decrease in the degree of linear polarization at large angles of incidence for 60^{o} zenith view angles on July 17 (the hook of the fishhook) is due to the heads (poor specular reflectors) decreasing the visibility of the flag leaves to the radiometer.

V. Conclusions

The specular reflection process has been shown to be a key aspect of radiation transfer by plant canopies. Polarization measurements have been demonstrated as the tool for determining the specular and diffuse portions of the canopy radiance. The magnitude of the specular fraction of the reflectance is significant compared to the magnitude of the diffuse fraction. Therefore, it is necessary to consider specularly reflected light in developing and evaluating light-canopy interaction models for these two wheat canopies. Models which assume leaves are diffuse reflectors correctly predict only the diffuse fraction of the canopy reflectance factor. The specular reflectance model, described here, when coupled with a diffuse leaf model, would predict both the specular and diffuse portions of the reflectance factor. The specular model predicts and the data analysis confirms that the single variable, angle of incidence of specularly reflected sunlight on the leaf, explains much of variation in the polarization data as a function of view-illumination directions.

Design of hardware to remotely sense the polarization of the light reflected by a canopy under a clear sky is simplified by the results of this research. First, the lack of fine structure in wavelength in the polarization spectra suggests that a design with a single wavelength band covering the entire visible wavelength is a possibility. Second, the angle of the polarization analyzer on the polarization sensor does not depend on the data but solely on view/illumination directions and can be set prior to data acquisition.


30.0
10.0
1.0
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0.003
R_Q, Reflectance Factor (%)
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80
70
60
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Zenith View Angle
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20
30
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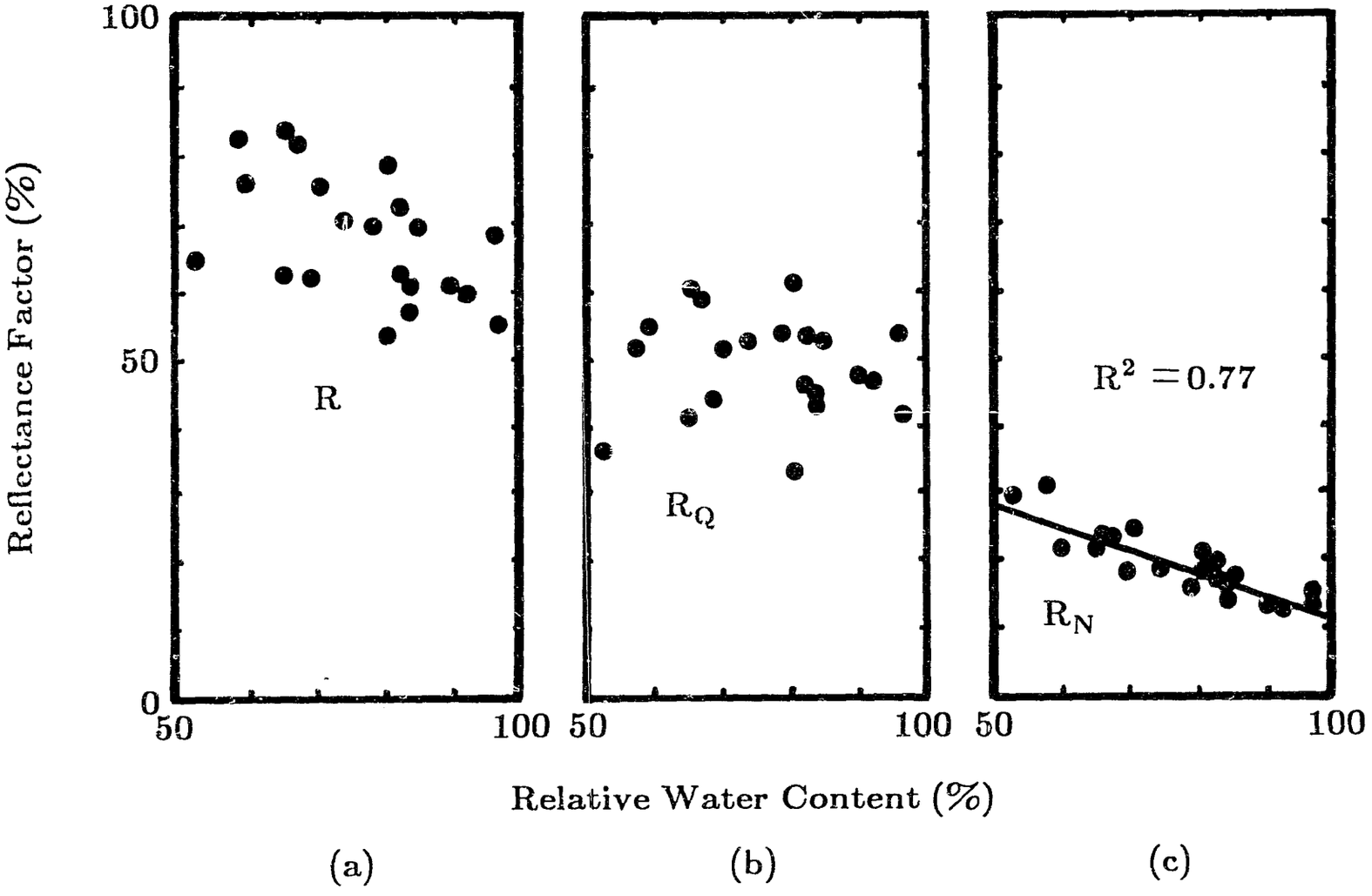
60
70
80
90
Angle of Incidence (degrees)


100
50
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50
100
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Reflectance Factor (%)
R
R_Q
$R^2 = 0.77$
R_N
Relative Water Content (%)
(a)
(b)
(c)

Linearly Polarized Light Reflected by Wheat Canopy

(0.66 μm)

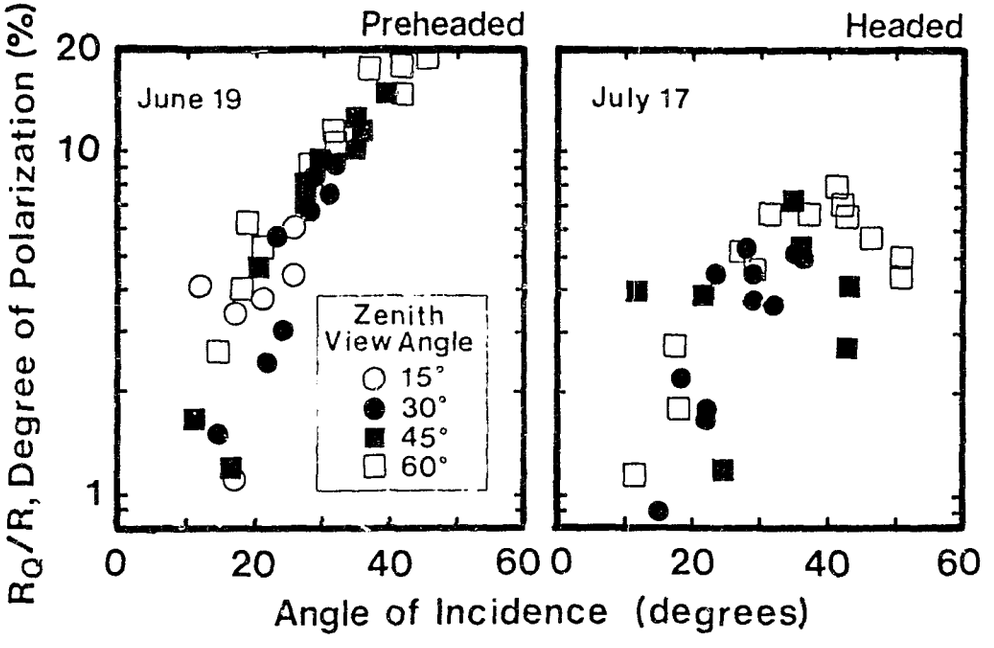

Fig. 3

N86-13799

GEOMETRIC-OPTICAL MODELING OF A CONIFER FOREST CANOPY

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Principal Investigator

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The primary objective of this research is to explore how the geometry of trees in forest stands influences the reflectance of the forest as imaged from space. Most plant canopy modeling that has been carried out thus far views the canopy as an assemblage of plane-parallel layers on top of a soil surface. For these models, leaf angle distribution, leaf area index, and the angular transmittance and reflectance of leaves are the primary optical and geometric parameters. Such models, and their derivatives, are now sufficiently well developed to explain most of the variance in angular reflectance measurements observed from homogeneous plant canopies. However, forest canopies as imaged by airborne and spaceborne scanners exhibit considerable variance at quite a different scale. Brightness values vary strongly from one pixel to the next primarily as a function of the number of trees they contain. At this scale, the forest canopy is nonuniform and discontinuous.

This research focuses on a discrete-element, geometric-optical view of the forest canopy. Trees are considered to be solid objects casting shadows on a contrasting plane. The brightness of a pixel is then a function of the background brightness, the number of trees in the pixel, the size and shape of the trees and the individual shadows they cast, and the chance overlapping of shadows and tree crowns that occurs when trees fall close together. This model of the forest canopy presents an alternative approach to canopy modeling that is well suited to applications of multispectral imaging by aircraft and spacecraft.

The primary objectives of this research are: (1) mathematical formulation of a discrete-element, geometric-optical model to explain the mean and pixel-to-pixel variance in reflectance of sparse to dense forest canopies; (2) testing of the formulation through Monte Carlo simulations and real image data; and (3) development of an inversion procedure to allow remote estimation of size, shape and spacing of trees from imagery when the imagery is too coarse to permit identification and measurement of individual trees.

As developed, the model considers conifers as cones (Fig. 1). Parallel-ray geometry is used to describe the

illumination of the three-dimensional cone and the shadow it casts on the background. Cones are assumed to be randomly placed and freely overlapping; their heights are assumed to be ognormally distributed. Both these assumptions are supported by literature studies and field work. For the initial model, the cones are assumed to be of a fixed shape determined by the apex angle; however, in application, the apex angle is allowed to vary and an effective apex angle is determined for the stand as a whole.

The research has been carried out in four overlapping phases, all of which are nearly complete. The first phase involved development of the basic mathematical model explaining the distribution of reflectance values expected for stands with given size, shape, and spacing parameters under fixed conditions of illumination. This phase included the development of an important general theorem in geometric probability describing the expected variance in random overlapping of shapes in the plane.

The second phase utilized Monte Carlo simulations of forest stands both to confirm the general theorem and empirically calibrate some parts of the model. As one part of the Monte Carlo modeling effort, the bidirectional reflectance of a pixel consisting of Lambertian cones on a background was simulated. The result (Fig. 2) showed many of the features of bidirectional reflectance distribution functions that have been observed for real forests.

The third phase involved assembling Landsat 80-m and SPOT simulation 10-m digital imagery for two test sites in northern California, and visiting the sites to collect ground data for model calibration and verification. The two sites contrasted a rather open stand of smaller, broader trees (pines) with a dense stand of taller, more narrow trees (red firs). Field measurements included recording the diameter and location of every tree within 12-16 circular subplots arranged on a grid at each site, as well as the collection of accurate heights and apex angles for a random subsample of trees within each subplot.

The fourth phase included the development of an inversion procedure to estimate stand parameters of tree size, shape, and spacing remotely through the observed distribution of brightness values for a stand, as well as the checking of the results against the field observations. For the two stands tested, the inversion procedure yielded good results. The 80-m imagery was less accurate for the denser of the two stands, whereas the 10-m imagery was generally better. The contrasts between the two stands emerged strongly at both resolutions in spite of some differences in observed and calculated parameter values.

Geometric-optical Modeling

The significance of this research is twofold. First, it establishes firmly that the three-dimensional geometry of ground scenes alone can explain much of the variance in digital imagery seen at resolutions typical of present and planned sensing instruments. This observation is widely applicable beyond forests to many other types of natural plant communities, as well as to any other scenes imaging three-dimensional objects, such as urban areas, suburban developments, etc. Second, it provides a method to directly parameterize the shape, size, and spacing of ground objects remotely even when such objects are below the level of resolution of the sensing instrument. The most obvious example is the remote estimation of forest biomass, which is a direct function of the shape, height, and density of the trees. Used in conjunction with quantitative relationships between spectral reflectance and leaf area index/standing biomass now being developed by other researchers, as well as with a stratified sampling procedure, this technique could greatly aid global understanding of carbon flows and cycles.

The future development of this research will have two main thrusts. First, more mathematical modeling is necessary to incorporate new crown shapes and mixtures of shapes, as well as to account for terrain effects. Second, more field testing is necessary to confirm the utility of the inversion procedure and extend the technique to vegetation types beyond conifer stands. These developments will not only improve our basic understanding of remotely sensed scenes, but also allow the direct extension of that improved understanding to relevant problems in remote sensing and global habitability.

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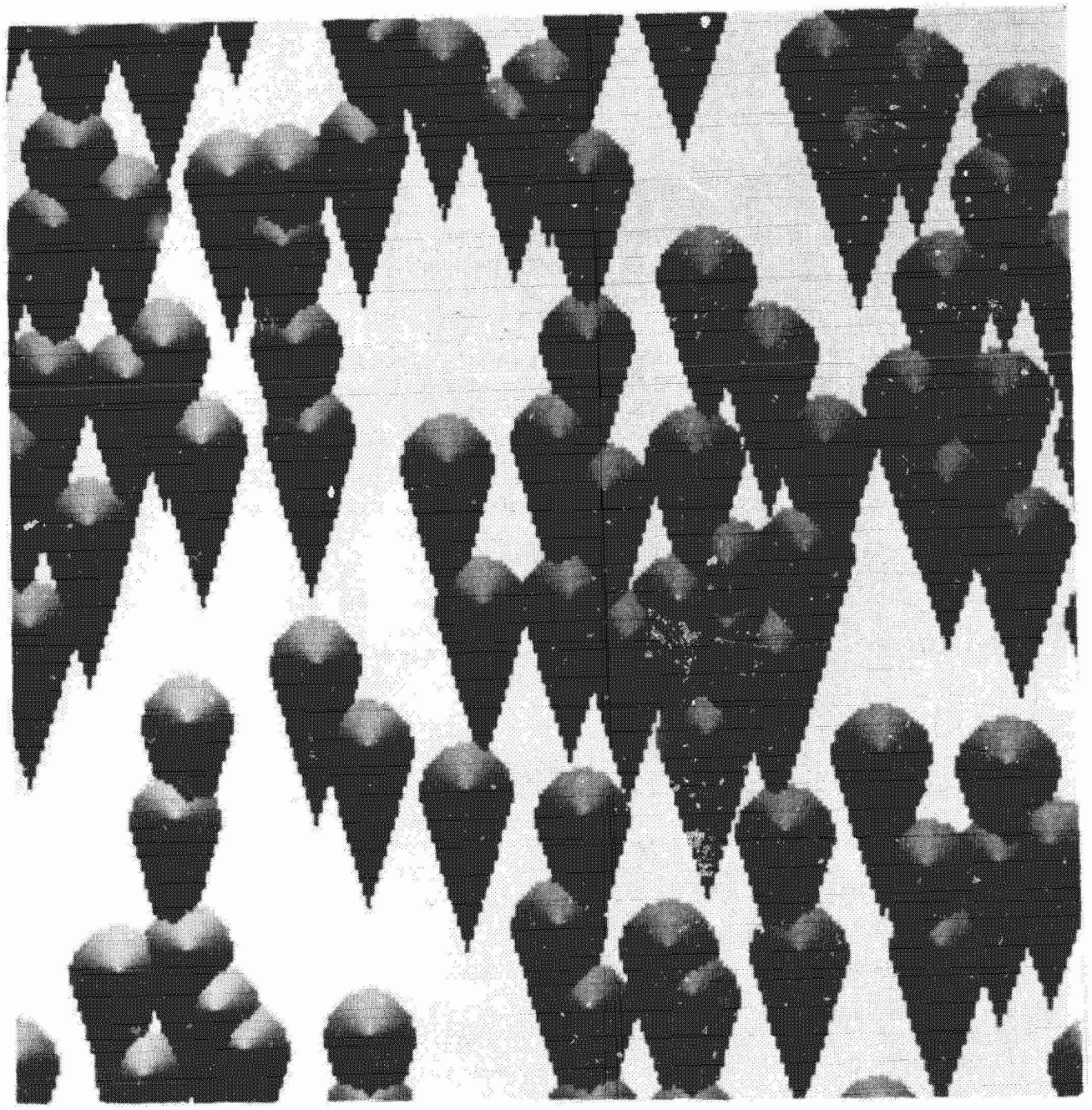

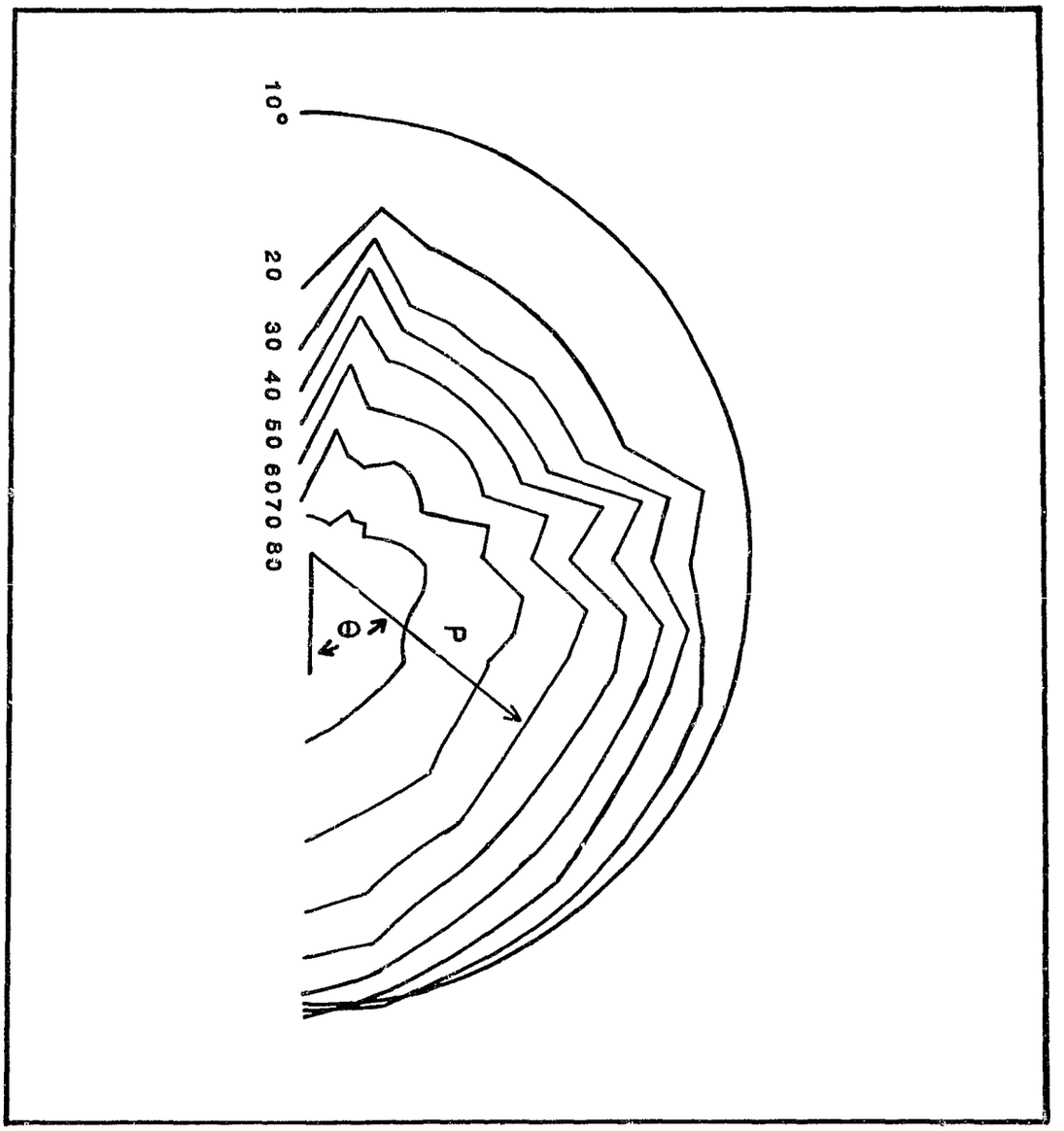
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N86-13800

CROP CHARACTERISTIC RESEARCH: GROWTH AND REFLECTANCE ANALYSIS

G. D. Badhwar
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Houston, TX 77058

Justification, Goals, and Objectives

Much of the early research in remote sensing follows along developing "spectral signatures" of cover types. It was, however, found that a signature from an unknown cover class could not be matched to a catalog value of known cover class. This approach was abandoned and "supervised classification" schemes followed. These were not efficient and required extensive training. It has been patently clear that data acquired at a single time could not separate cover types.

A large portion of the proposed research has concentrated on modeling the temporal behavior of agricultural crops and on removing the need for any training data in remote sensing surveys--the key to which is the solution of the so-called "signature extension" problem.

A clear need to develop spectral estimaters of crop ontogenic stages and yield has existed even though various correlations have been developed. Considerable effort in developing techniques to estimate these variables was devoted to this work.

The need to accurately evaluate existing canopy reflectance model(s), improve these models, use them to understand the "crop signatures," and estimate leaf area index was the third objective of the proposed work.

The next section gives a synposis of this research effort.

Technical Approach

The technical approach consisted of first developing an accurate model that would describe the temporal development of various spectral transforms with time, henceforth called a profile, that would depend primarily on crop characteristics. It would thus permit features to be extracted from real spectral data that describes a specific crop and would not depend on external variables such as row direction, sun zenith angle, the atmospheric state, etc. Having extracted a very small set of features use the canopy reflectance model(s) to gain (a) better understanding and limitations of existing canopy models, (b) use the model(s) to accure a deeper physical understanding of why these features permit crop separation and develop method(s) of deciding, a priori, what features would permit crop separation, and (c) explorate the applicability of these models to natural forest communities.

Results

The current research effort has shown that the Kauth-Thomas (K-T) greenness, in the spectral space of both the multispectral spectral scanner or the thematic mapper, can be described by a model of the form,

$$\rho(t) = \rho_o + (\rho_m - \rho_o) \left(\frac{2\beta e}{\alpha} \right)^{\alpha/2} (t - t_o)^{\alpha} \text{ Exp } [-\beta(t - t_o)^2] \quad (1)$$

where $\rho(t)$ the K-T greenness as a function of time, ρ_m, the maximum value of greenness reached at time of peak greenness

$$t_p - t_o = \sqrt{\frac{\alpha}{2\beta}} ,$$

ρ_o the value of soil greenness at times at and before emergence, t_o, and α and β are two crop and condition specifics constant. These two constant are related to the inflection points of the profile

$$t_1 - t_o = \left[\frac{(2\alpha + 1) - \sqrt{8\alpha + 1}}{4\beta} \right]^{1/2}$$

$$t_2 - t_o = \left[\frac{(2\alpha + 1) + \sqrt{8\alpha + 1}}{4\beta} \right]^{1/2}$$

This research effort has established that the peak greenness above the soil line, $G_{max} \equiv \rho_m - \rho_o$, the separation

$$\sigma \equiv t_2 - t_1 = \left\{ \frac{1}{2\beta} + \frac{\alpha}{2\beta} \left[1 - \left(1 - \frac{1}{\alpha} \right) \right] \right\}^{1/2}$$

and the time of peak greenness, t_p, are three characteristics or features that carry 95% of all information (Fisher information criteria) available in both spectral and temporal data and has led to a drastic reduction in the number of variables and a simplification of classifier design.

Figure 1 shows the power of these features in separating two summer crops, corn/soybeans, based on data extracted from the thematic mapper. The axis out of the plane of paper is the number of pixels, the other two axes being G_{max} and σ in days. The distributions are more or less gaussian and provide excellent separability. Not only has it been shown that these features (G_{max}, σ, and t_p) are applicable to different sensor systems but are truly "signature extendable" over vast areas in the United States and, for the first time ever in remote sensing, to areas in Argentina. In particular, it has been found that, (i) G_{max} (soybeans) > G_{max} (corn), (ii) σ (soybeans) < σ (corn), and (iii) t_p (soybeans) > t_p (corn).

It has been shown that the cardinal points t_1, t_p, and t_2 are related to three specific ontogenetic stages of a crop. This has been shown to be case for wheat, barley, corn, and soybeans and appears to be true for rice also. This, then permits, a priori, calculation of these stages from an agrometeorological model and in complete automation of crop classification.

It has also been shown that integral,

$$\int_{t_1}^{t_2} \rho(t)dt,$$

which acts in a manner very similar to the leaf area duration, is strongly correlated to yield in the case of both corn and soybeans. More research in this direction is called for; however, the potential of a true integrated, automatic, and objective crop production system applicable to global corn and soybean areas seem within grasp.

In order to understand the reasoning behind why G_{max} (soybeans) > G_{max} (corn) almost universely, the existing canopy reflectance models were used. Figure 2, shows a two dimensional histogram of the G_{max} and leaf area index, calculated using the SAIL model. The distribution for each crop was obtained by varying soil types (12 covering the world soil reflectances) and fourteen different leaf angle distribution for a total of 168 different calculations in each distribution. These calculations show that if the leaf area index of these crops is greater than about 4, the primary reason of their separability is because corn is C_4 plant and soybeans is C_3 plant and their leaf reflectance and transmittance are intrinsically different. Differences in soil type and leaf angle distribution simply require a somewhat larger difference in the two leaf area indices to get the same separation. These results have also established that if the input to the canopy model such as leaf optical properties, soil reflectance, etc. for two crops is known, a transform and optimum observation period to provide a given level of separability can be calculated, a priori.

The existing canopy reflectance models had not been subjected to a good test, particularly for off-nadir view angle. In order to acquire a degree of confidence in the models and their predictions, the homogenous SUITS, SAIL, and CUPID canopy reflectance models were very carefully evaluated for canopies of corn and soybeans. All of these models captured the salient features of the canopy reflectance, with the SAIL model showing the best overall performance. However, it was found that it is necessary to include the specular directional characteristics of leaves into these models. Figure 3 shows the performance of the SAIL model before and after the inclusion of leaf specular reflectance systematic angular deficiencies of this model are substantially removed. This should improve the usefulness of these models, to evaluate key biophysical parameters, such as leaf area index. Considerable effort has been devoted in evaluating these models for coniferous canopies such as Black Spruce, Jack Pine, Red Pine, White Pine, and Ponderosa Pine with little success, partly due to lack of input data on key input parameters; however, their performance on Aspen and Birch canopies appear to be much better. We have also found that the temporal profile of an Aspen canopy can be adequately represented by an equation of the form (1). The meaning of the t_1, t_p, and σ would of course be very different.

Significance

(1) For the first time in remote sensing, crop features have been found that are truly "signature extendable." In case of corn and soybeans they have been shown to be applicable to vast geographic regions of the United States for four years 1978, 1979, 1980, and 1982 and are extendable to Argentina. Based on SAIL canopy reflectance model, the reasons for this applicability have been understood.

(2) It has been shown that critical ontogenetic crop stages can be estimated from spectral data. Based on this work and more detailed work, it is suggested that it may be more accurate to estimate crop phenology using spectral data than current methods.

(3) Preliminary evidence suggests that the area of greenness profile from t_1 (when new leaf development stops) to t_2 (dent) is strongly correlated to yield.

The above three results have made it possible to seriously consider an automatic and objective crop production system.

(4) An improved canopy reflectance model has been developed that includes the leaf specular component.

(5) The effectiveness of these models in estimation of leaf area index of wheat, corn, and soybeans and recently in study of forest species separation and aspen leaf area estimation has been demonstrated.

Future

Most of the current work on feature extraction, ontogenetic stage and yield has been done on corn and soybean. Some start was made on wheat, barley, and oats. The work on spring grains should be intensified. Currently, no technique exists to separate the three crops. Additional work on ontogenetic stage and yield of corn and soybeans still needs to be done.

The performance of existing canopy models on forest canopies has been found to be sadly lacking, much more so for coniferous forest than for decidous forest. Major improvements in these models are called for and a corresponding adequate input data set must be collected. Techniques to estimate leaf area index or phytomass of vegetation cannot be developed realiably without such an effort.

ORIGINAL PAGE IS
OF POOR QUALITY

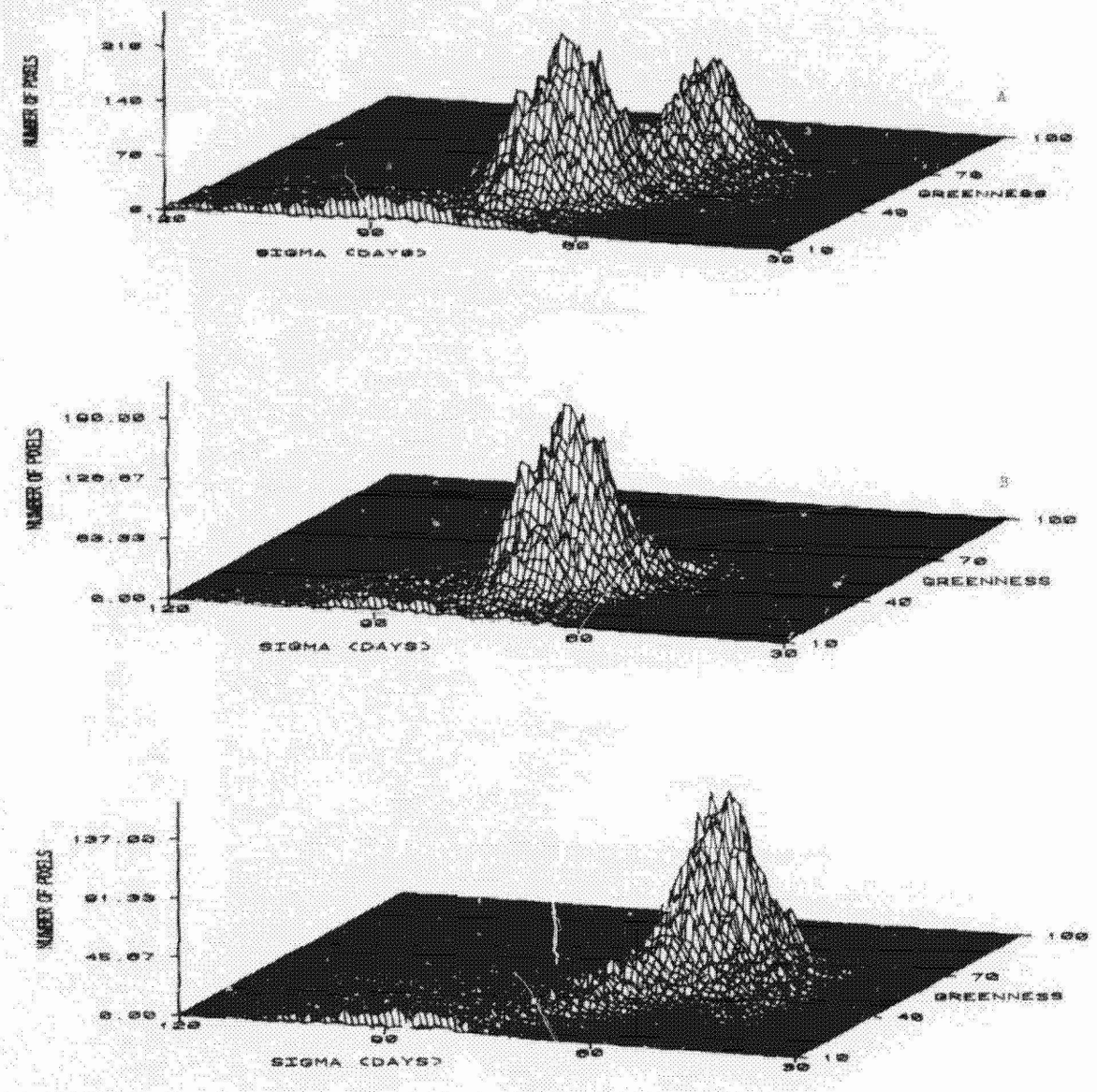


Figure 1

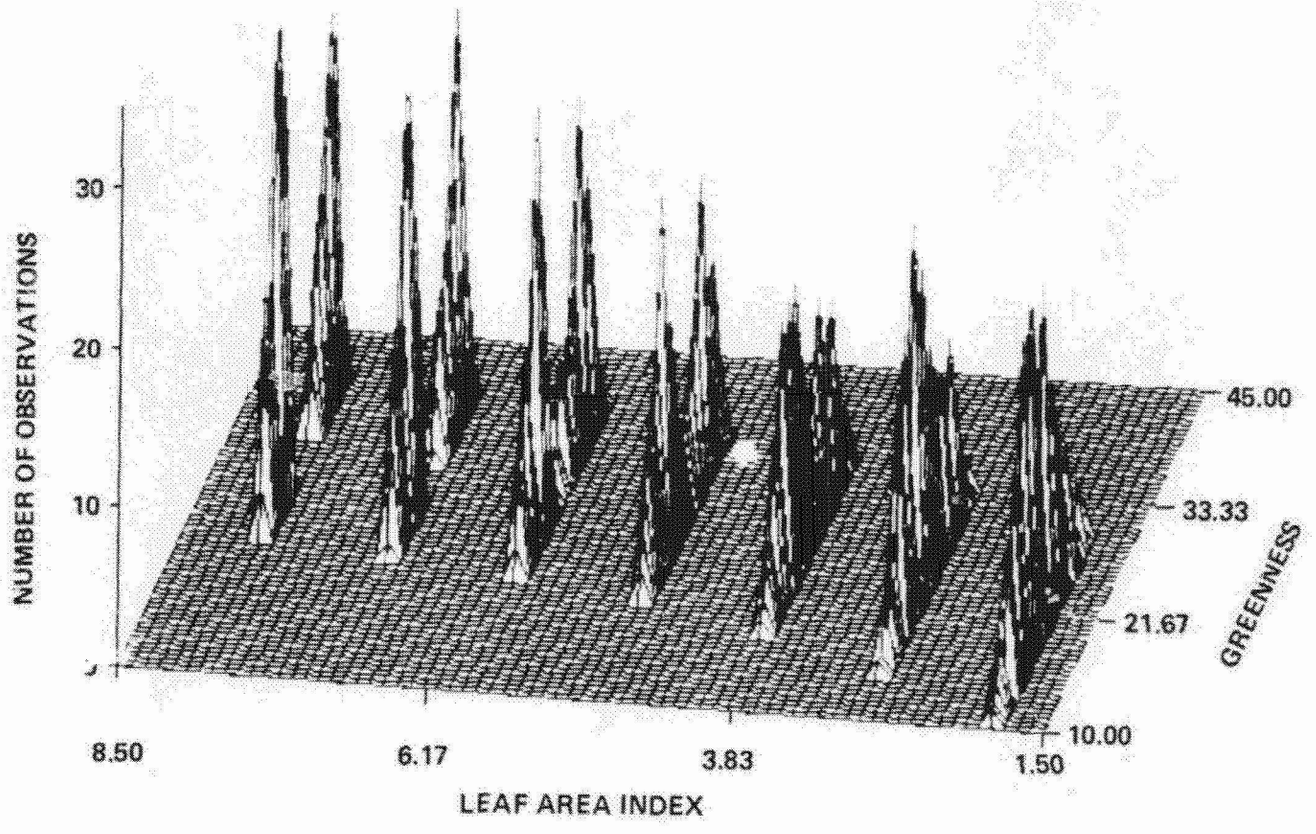
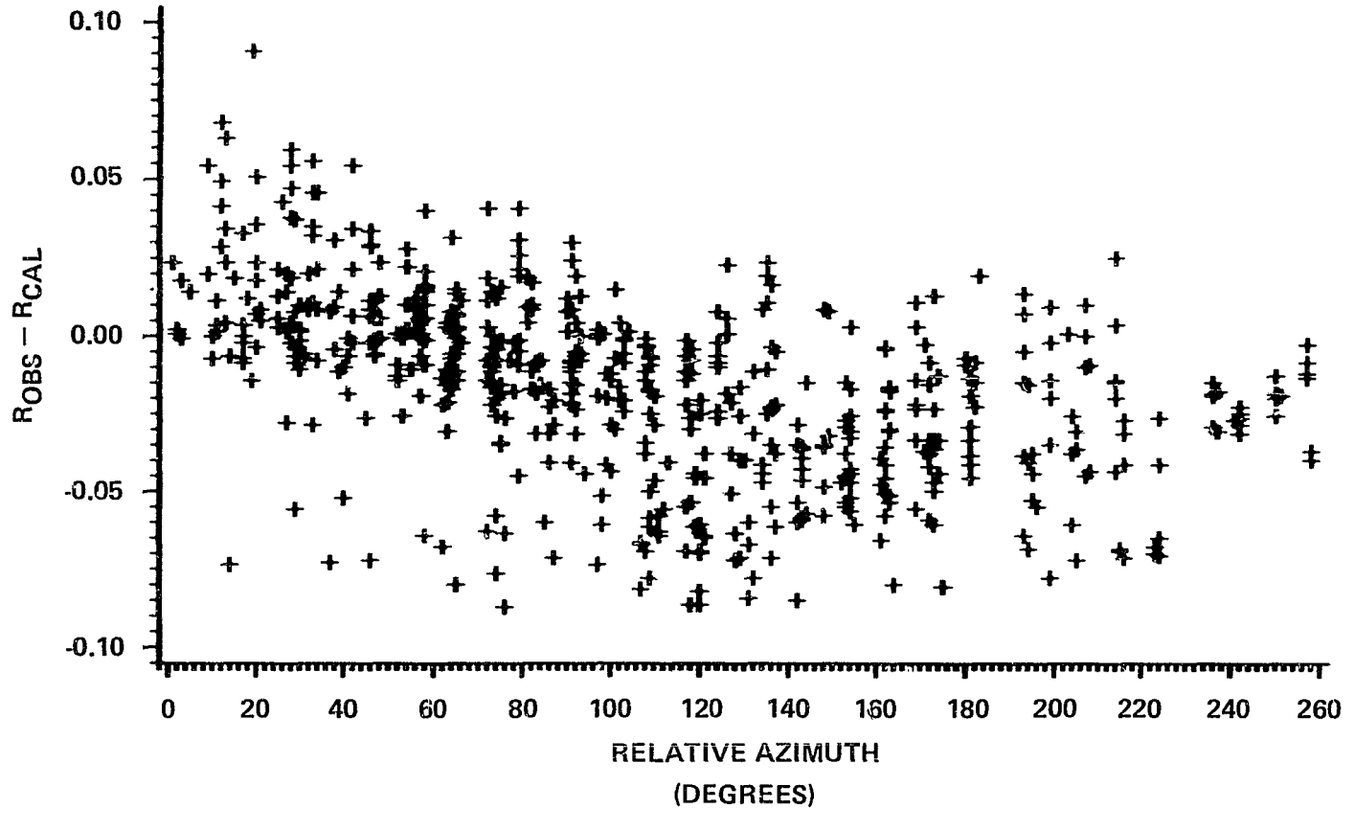

NUMBER OF OBSERVATIONS
30
20
10
8.50
6.17
3.83
1.50
LEAF AREA INDEX
45.00
33.33
21.67
10.00
GREENNESS

Figure 2


0.10
0.05
0.00
-0.05
-0.10
$R_{OBS} - R_{CAL}$
0
20
40
60
80
100
120
140
160
180
200
220
240
260
RELATIVE AZIMUTH
(DEGREES)

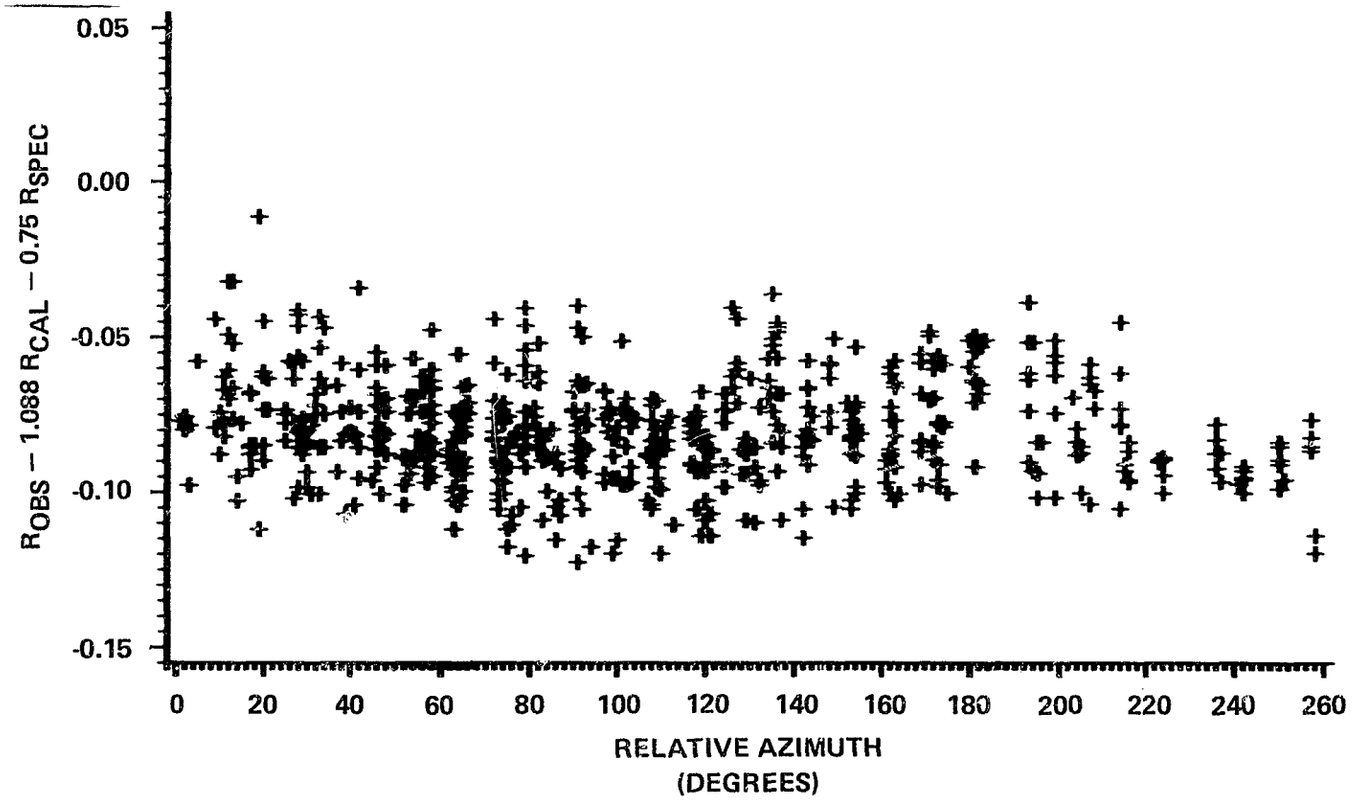

0.05
0.00
-0.05
-0.10
-0.15
$R_{OBS} - 1.088\ R_{CAL} - 0.75\ R_{SPEC}$
0
20
40
60
80
100
120
140
160
180
200
220
240
260
RELATIVE AZIMUTH
(DEGREES)

 FIGURE 3

N86-13801

GROUND REFLECTANCE MEASUREMENTS FROM THEMATIC MAPPER DATA

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1. Background - Satellite radiance data are measures of solar radiation that has been reflected by the Earth's surface and scattered and absorbed by atmospheric gases and aerosols. Of concern to geologists are the surface reflectance and the degrading effects on surface resolution and albedo contrast introduced by atmospheric phenomena. The objects of the presently-described research have been to: (1) provide an empirical relationship between scanner radiance and ground reflectance allowing interpretation of the satellite data in terms of the surface parameter, (2) assess the precision with which surface spectral reflectance may be recovered from Landsat-4 TM data in the presence of perturbing atmospheric and instrumental factors. Our approach is field-oriented, and utilizes ground observations of surface spectral reflectance with portable spectrometers and radiometers to develop the required empirical relationships.

2. Method - For a satellite scanner system over locally uniform ground with homogeneous atmosphere above the upward directed radiance is given by (Chandrasekhar, 1960; Gordon, 1976; Pearce, 1977).

$$I = I_1 + \frac{R}{1-Rs} I_2 \qquad (1)$$

where the first term (I_1) represents radiation from the atmosphere alone, and the second term radiation that interacts both with the atmosphere and the surface. R is the uniform Lambertian surface reflectance, s is a parameter describing the overall probability of backscatter from the atmosphere after reflection by the ground, and I_2 the overall probability of transmission by the atmosphere after reflection by the ground. All quantities in (1) are functions of wavelength. The determination of R from equation (1) requires measurement of the functions I_1, I_2, and s. In principle this may be carried out by theoretical study of model atmospheres, provided information is available on concentration and distribution of aerosols as well as the absorbing gas species present. These data are not however generally available for the times and places of satellite data acquisition.

We illustrate here an alternative method wherein the required parameters of equation (1) are determined empirically using ground-based measurements of spectral reflectance. The image data set used is the TM scene for Wind River Basin, Wyoming (acquired November, 1982). The scene covers an area of 32,400 km^2 of central Wyoming. The atmosphere is largely free of clouds and haze, which is typical of scenes ordinarily used for geologic remote sensing. Snow blankets higher parts of mountains surrounding the basin.

3. Results for Surface Spectral Reflectance - Field spectral measurements of surface bidirectional reflectance were made for selected targets throughout the Wind River TM scene using a portable reflectance spectrometer (Conel, et al., 1985). Image radiance values, expressed in digital number (DN) were determined for each of the field sites. Scatter plots of image DN versus surface reflectance averaged over bandpasses of the

TM were prepared and are shown in figure 1. After conversion of the DN to energy units the term I_1 is obtained as the intercept value at R = 0, and the value of I_2 from the slope. These plots are found to be linear with correlation coefficients of 0.96 or greater for all channels of the TM. It is also possible to obtain good fits using parabolic equations. Quasi-parabolic functional behavior would indicate a contribution to the radiance from the multiple reflection factor 1/(1-Rs) and would provide a means for determination of s directly from the curvature term. Based on statistical analysis of these various possible fits to the data, the presence of nonlinear terms in equation (1) cannot be established. For the atmospheric conditions prevailing during time of satellite data acquisition we conclude that the term s is negligible compared to unity, and that the linearized form of equation (1) is appropriate.

To illustrate application of the method for recovery of ground reflectance outside the calibration areas we present a comparison between image-derived spectra and measured field reflectance spectra for five areas throughout the Wind River TM scene (Figure 2). The chronology of events for gathering the data was as follows: (1) the original TM scene was obtained in November, 1982, (2) field measurements were obtained in November of 1983 and used to construct the calibration lines of Figure 1, (3) field measurements using portable spectrometers and a hand-held broadband radiometer of the additional "unknown" areas were obtained in July, 1984. Thus the comparisons involve measurements spanning a period of approximately two years. Agreement between the two sets of observations is excellent to good. It is expected that the comparisons could be improved if the time interval between satellite and field measurements could be shortened. Two additional factors undoubtedly contribute to the differences observed. First, field sites were chosen that were homogeneous and (except for Riverton High School lawn) unvegetated. Despite precautions the best natural targets are always inhomogeneous at the level of a few percent reflectance, and we must rely upon a limited sampling to provide representative reflectance data. Second, some targets are small and it is often difficult to locate them accurately in the images. Factors that are likely to contribute second order effects include those of so-called adjacency effects, phase effects in the surface reflectance, and the comparison of bi-directional versus Lambertian surface reflectance functions. Adjacency effects reduce contrasts between contiguous areas of differing surface reflectance. Kaufman and Joseph (1982) have provided some numerical examples. These problems can be minimized by making measurements far from the edges of large areas of differing albedo, but this is not usually possible in practice. For optically thin conditions (optical depth on the order of 0.2 or less) the effects may amount to a relative change in brightness of a percent (see Kaufman and Joseph, 1982). Relative effects of this magnitude will be difficult to detect (see below) let alone correct for in image data. These effects may influence both the calibration relationships as well as the determined brightness values for isolated pixels in the scene. Phase effects in the surface reflectance can be minimized by taking field measurements at the same phase angle and solar elevation as characterize the satellite observations. The third problem of interpreting satellite-determined reflectance as bi-directional is not considered serious for the present observations since the atmosphere, especially at longer wavelengths, was optically thin.

Considering the possible complications, agreement between measured and satellite-determined reflectance properties is remarkably good. This lends support to the assumption, implicit in Equation 1, of homogeneity of the atmosphere over large areas of the scene during the time of satellite data acquisition. The measured surfaces also appeared to have been stable over the time span of satellite and field data acquisition.

4. Sensitivity of the TM-derived measurements of reflectance - By differentiating Equation (1) with respect to R (Gordon, 1976) a basis is provided for determining what differences in spectral reflectance ΔR may be obtained from TM scanner data, including effects of both atmosphere and precision of scanner irradiance measurements ΔI. The TM system signal-to-noise ratio (i.e., $I/\Delta I_N$ for all visible and near infrared bands can be expressed as a linear function of the irradiance I (Barker, et al., 1983), i.e., $I/\Delta I_N = A + BI$ where the A and B are known constants, and ΔI_N is the noise-equivalent irradiance of the scanner. An expression for ΔR including the signal/noise ratio can then be written down. Figure 3 shows the results of calculations for such noise-limited reflectance differences for all bands of the TM scene of Wind River Basin. The values of I_1 and I_2 are derived from the data given in Figure 1. Based on these calculations, the intrinsic sensitivity of the TM system to detection of changes in reflectance everywhere in the scene less than about 1%.

The actual detectable reflectance differences may be limited by instrumental gain. These differences $\Delta R'$ are given by $\Delta R' = 1/(dDN/dR)$, which is the reciprocal slope of a calibration line in Figure 1. The values of $\Delta R'$ obtained in this way for the calibration data in Figure 1 are comparable to those obtained accounting for the measured pre-flight signal/noise ratio of the TM system together with the atmospheric attenuation factors (Figure 3). The present gain settings of the TM system are thus consistent with the actual noise characteristics of the TM.

5. Significance of Results - We have employed an approximate analysis of the real terrestrial atmosphere and surface (embodied in Equation 1) to investigate the question of recovering surface reflectance from TM radiance data, and to estimate the uncertainties present in such determinations. It was shown that the surface reflectance could in the best examples be recovered to within a few percent, and it is expected that these estimates could in principle be improved by better sampling procedures. The theoretical limit on such determinations was shown to be about a percent for the TM system. Equation 1 and its empirically determined constants can be used in conjunction with sharp edges in the image to estimate the atmospheric portion of the system modulation transfer function (MTF). I_1 and I_2 in Equation 1 can be thought of as functions of the optical depth and phase function for a homogeneous model, and the numerical values obtained as slope and intercept used to estimate these parameters for an optically thin atmosphere. These determinations have been made for the present data set, but space has not permitted a discussion of the results. They along with other results will be set out in forthcoming papers. It also appears possible to provide independent estimates of optical depth and scattering albedo using the so-called "two-halves" method of Kaufman (1982), which will provide an interesting comparison with the present results.

6. Future Research - Despite emphasis placed on interpretation of satellite-acquired scanner data, aircraft scanner systems like TMS and AIS continue to provide essential data sets for the study of many geologic and geobotanical problems. The aircraft observations provide useful high spatial resolution and (for TMS) encompass a wide range of surface viewing directions. We will study the problem of correcting aircraft data for atmospheric effects, and provide methods for looking at directional properties of the surface independent of the atmosphere for one or two test sites. The approach will emphasize "field" determination of atmospheric parameters along lines indicated above, together with observation of directional atmospheric scattering from the aircraft data themselves as inputs to modeling programs.

7. References

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Kaufman, Y.J., and J.H. Joseph, 1982, J. Geophys. Res., 87(C2), 1287-1299.

Pearce, W.A., 1977, Rep. 004-77, EG&G/Washington Anal. Serv. Center, Riverdale, Maryland, 136 pp.

8. Figure Captions

Figure 1: DN vs. Reflectance Calibration Curves. TM-4, Wind River Basin, Wyoming, Nov., 1982.

Figure 2: Comparison of TM-4 and Field Spectra, Wind River Basin, Wyoming.

Figure 3: Noise-Limited Uncertainty ΔR Derived from TM-4, Wind River Basin, Wyoming.

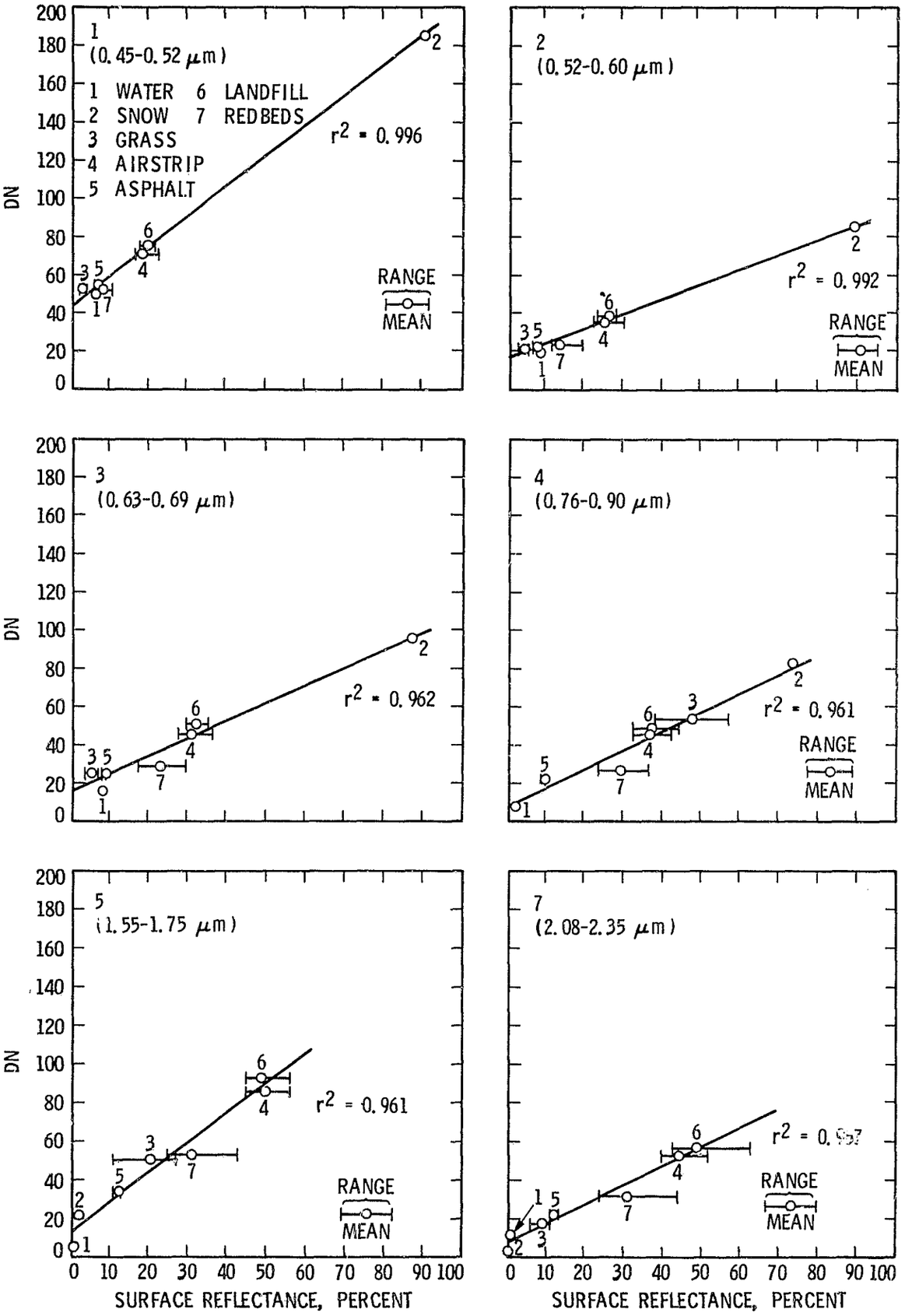
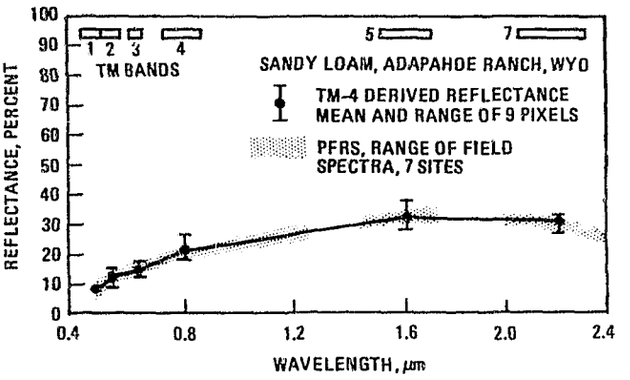
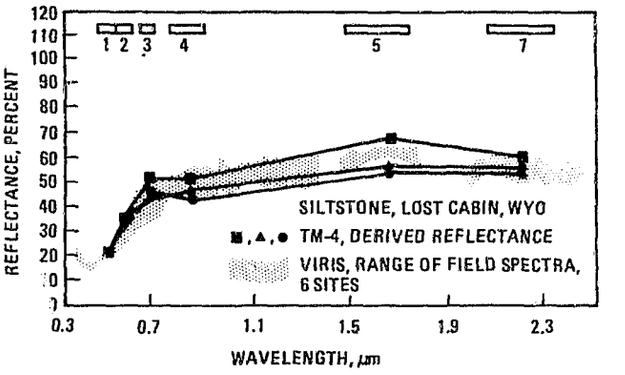
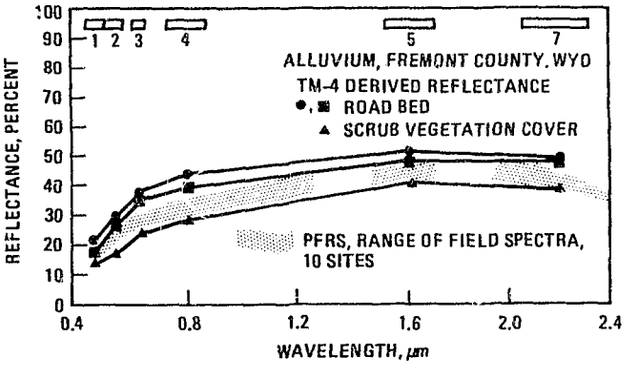

1
(0.45-0.52 μm)
1 WATER 6 LANDFILL
2 SNOW 7 REDBEDS
3 GRASS
4 AIRSTRIP
5 ASPHALT
r² = 0.996
RANGE
MEAN
2
(0.52-0.60 μm)
r² = 0.992
RANGE
MEAN
3
(0.63-0.69 μm)
r² = 0.962
4
(0.76-0.90 μm)
r² = 0.961
RANGE
MEAN
5
(1.55-1.75 μm)
r² = 0.961
RANGE
MEAN
7
(2.08-2.35 μm)
r² = 0.957
RANGE
MEAN
DN
SURFACE REFLECTANCE, PERCENT
0 10 20 30 40 50 60 70 80 90 100
0 20 40 60 80 100 120 140 160 180 200

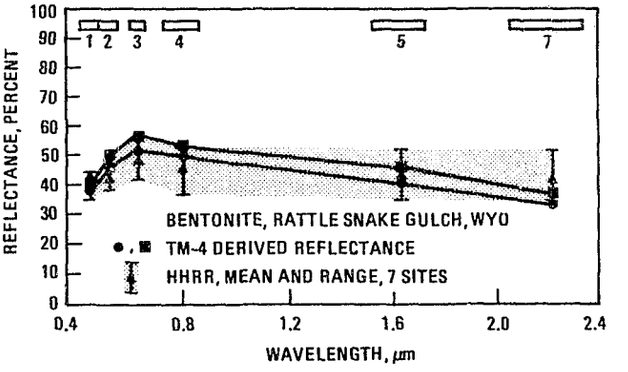
Figure 1

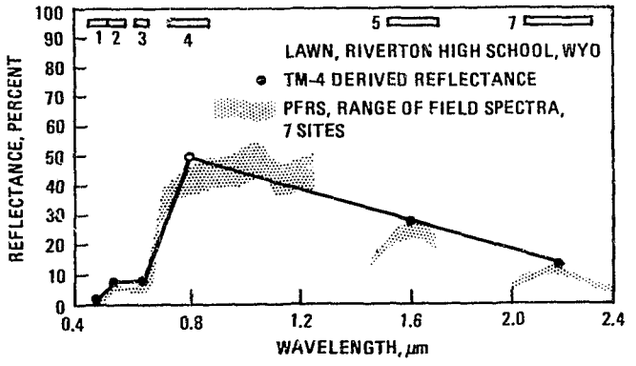
COMPARISON OF TM-4 AND FIELD SPECTRA, WIND RIVER BASIN, WY.


TM BANDS
SANDY LOAM, ADAPAHOE RANCH, WYO
TM-4 DERIVED REFLECTANCE MEAN AND RANGE OF 9 PIXELS
PFRS, RANGE OF FIELD SPECTRA, 7 SITES
REFLECTANCE, PERCENT
WAVELENGTH, μm









TM-4 IMAGE CALIBRATION, NOV., 1983

FIELD SPECTRAL DATA REQUIRED JULY, 1984

Figure 2

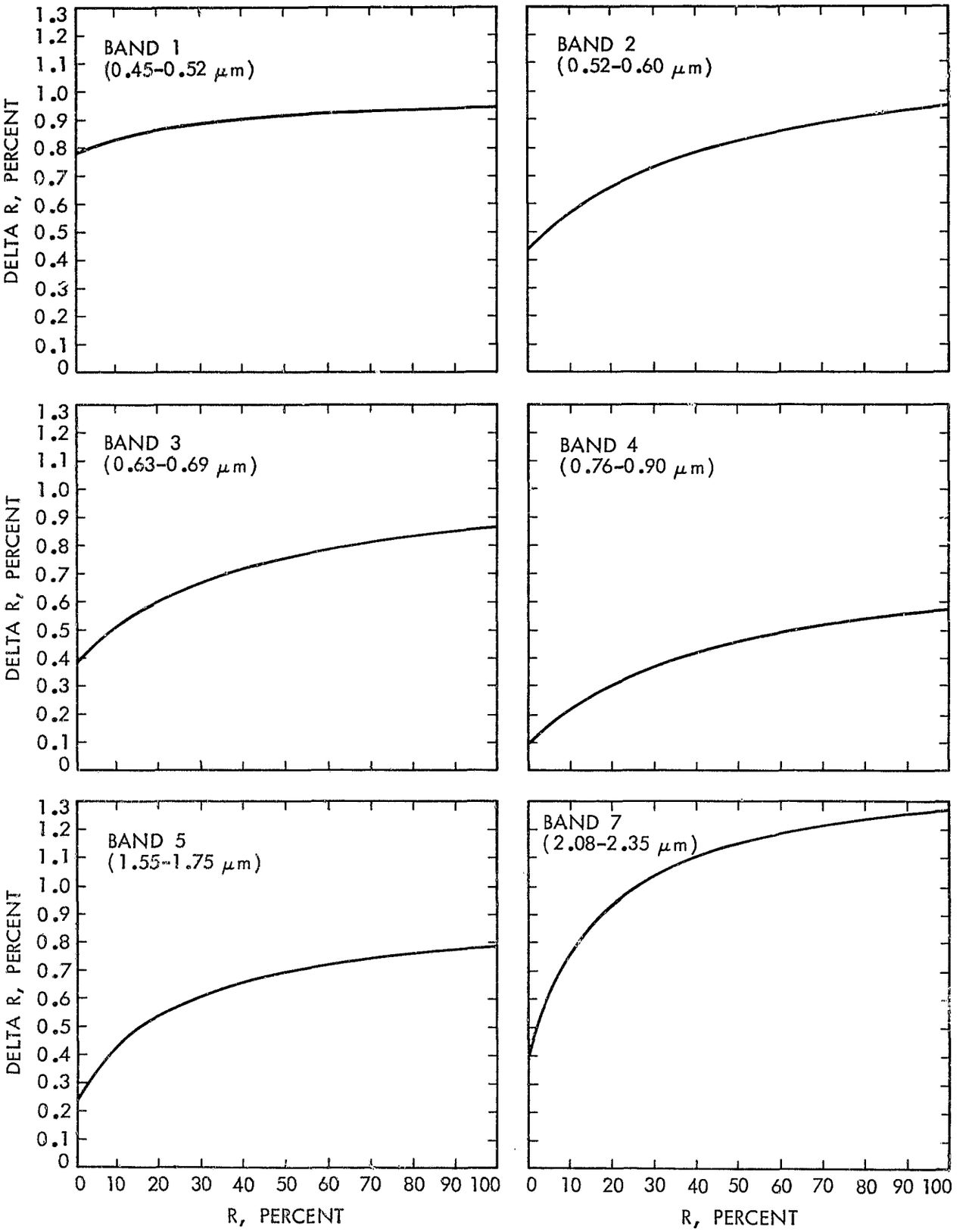

BAND 1
(0.45-0.52 μm)
BAND 2
(0.52-0.60 μm)
BAND 3
(0.63-0.69 μm)
BAND 4
(0.76-0.90 μm)
BAND 5
(1.55-1.75 μm)
BAND 7
(2.08-2.35 μm)
DELTA R, PERCENT
R, PERCENT
0 10 20 30 40 50 60 70 80 90 100
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3

Figure 3

N86-13802

Thermal Infrared Geologic Remote Sensing Research at the Jet Propulsion Laboratory

Mary Jane Bartholomew and Anne B. Kahle
January 29, 1985

JUSTIFICATION

Remotely sensed thermal infrared spectral data have great potential to improve rock type discrimination if the factors that control thermal infrared spectral reflection and emission can be better understood. Improved rock type discrimination in turn leads to better and more efficient geologic mapping which is carried out in the exploration, assessment and documentation of mineral resources and geologic hazards. Geologic maps also contribute significantly to the understanding of the natural history of the earth and neighboring planetary bodies.

OBJECTIVES

The particular goal is to study the spectral emission and reflection behavior of rock materials (rocks, rock weathering products and soils) as a function of earth-like environment and occurance. Some of the important environmental variables that influence the earth's near surface thermal regime and hence its thermal emission are sky temperature, sky field of view, microclimatology, time of day and season of the year. In addition, chemical and physical factors, mineralogy, particle size, surface roughness, presence of desert varnish and rock weathering, play a role.

APPROACH

The approach involves both field and laboratory investigations. The field work is divided between airborne and ground based studies. Remotely sensed mid-infrared spectral data of the earth can be acquired by the airborne Thermal Infrared Multispectral Scanner (TIMS) (Kahle and Goetz 1983; Palluconi and Meeks, 1985). TIMS measures normal spectral radiance of the earth's surface. It has six channels from 8 to 12 μm and is flown in a NASA Lear Jet. (Within this range the transmission of the earth's atmosphere is good and intense absorption features are present in surface silicate materials.) Computer image enhancement research is a significant part of TIMS investigations.

The ground based field work is carried out with the Portable Field Emission Spectrometer (PFES) which is used to make normal spectral radiance measurements from 3 to 14 μm. This JPL-built instrument is mounted and carried by backpack. The PFES has a spectral resolution of approximately .2 μm which makes it an important tool that can be used in interpreting TIMS data.

However, some scientific questions in this subject require the kind of experimental control that can only be provided in the laboratory. For example, the influence of earth-like near surface thermal gradients, desert varnish, rock weathering, particle size and surface roughness on the spectral emission of rock materials needs to be understood and can only be studied in

an environment that is free from variations in sky temperature, microclimotology, and sky field of view and uneffected by the season of the year or the time of day.

Therefore, we are developing the capability to measure in the laboratory the normal spectral radiance or rock materials at ambient temperatures (~ 20°C). This involves the careful design and construction of a sample accessory, called the emissivity cold box, for a commercial Fourier Transform infrared spectrometer that allows control and stabilization of sample temperature while shielding it from background radiation, (Brown and Young, 1975; Aronson and Enslie, 1973; Logan and Hunt, 1970; Conel, 1969; Low and Coleman, 1966; Lyon, 1965). A schematic diagram of the sample accessory is shown in Figure 1.

Liquid nitrogen will be used to control the temperature of the walls of the cold box and dry gaseous nitrogen will control the sample temperature. The temperature of the gaseous nitrogen will be controlled by a liquid bath. A separate liquid bath will be used to control the temperature of gaseous nitrogen that purges the spectrometer's optic bench.

The cold box will take the place of the spectrometer's source mirror during the measurement of sample radiance. Modifications to the spectrometer that allow this are already complete. Furthermore, the spectrometer's standard pyroelectric detector has been replaced by a more sensitive liquid nitrogen cooled mercury-cadmium-telluride detector.

With this configuration the sample radiance at the detector can be characterized as

$$L(\lambda,T_1) = K(\lambda)\,[\varepsilon(\lambda)\,W(\lambda,T_1) + R(\lambda) + S(\lambda)] \quad (1)$$

where $L(\lambda,T_1)$ = radiation at detector

T_1 = temperature of sample

$K(\lambda)$ = instrument resonse function

$\varepsilon(\lambda)$ = emissivity of sample

$W(\lambda,T_1)$ = black body radiation at temperature T_1

$R(\lambda)$ = radiation reflected by sample

$S(\lambda)$ = background radiation

then by making these additional measurements,

$$L(\lambda,T_2) = K(\lambda)[\varepsilon(\lambda)\,W(\lambda,T_2) + R(\lambda) + S(\lambda)] \quad (2)$$

$$B(\lambda,T_1) = K(\lambda)[W(\lambda,T_1) + S(\lambda)] \quad (3)$$

$$B(\lambda,T_{LN2}) = K(\lambda)\,S(\lambda) \quad (4)$$

where T_2 = temperature of sample different from T_1

T_{LN2} = temperature of liquid nitrogen

$B(\lambda,T_1)$ = radiation at detector from blackbody at temperature T_1

the sample emissivity can be calculated as follows.

$$\varepsilon(\lambda) = \frac{L(\lambda,T_1) - L(\lambda,T_2)}{B(\lambda,T_1) - B(\lambda,T_{LN2})} \cdot \frac{W(\lambda,T_1)}{W(\lambda,T_1) - W(\lambda,T_2)} \qquad (5)$$

All values in equation 5 are either measured or calculated from Plank's Law once the temperature of the sample is known.

Two techniques will be used to determine the sample's temperature. First, thermocouples will be located on or near the top and bottom surfaces of the sample. Second, the surface temperature will be computed from the radiance at the sample's Christiansen frequency (Conel, 1969; Arenson et al., 1969).

RESULTS

An example of TIMS data from Death Valley, California is given in Figure 2. These images show variation in emittance across part of the Panamint Mountains, valley floor and part of the Funeral Mountains. The light areas indicate high emittance and the dark low emittance. The values upon which the images are based were calculated from Plank's Law and TIMS data. These data have been used to make lithologic maps of bedrock and alluvial fans in Death Valley (Kahle and Goetz, 1983; Gillespie, Kahle and Palluconi, 1984).

Figure 3 shows PFES data from Death Valley. The silicate absorption doublet from 8 to 10 μm can be clearly seen in the quartzite spectra. This feature is only hinted at in the spectra of the volcanic rocks. The presence of the absorption features at 6.5 and 11.5 μm clearly indicate the carbonate nature of the dolomite example.

FUTURE PROSPECTS

We will evaluate the geologic utility of multispectral thermal infrared data using TIMS, and we will determine the lithologies that can be effectively discriminated on the basis of TIMS measurements, either alone or in combination with other remotely sensed data sets. Our laboratory studies will be directed towards understanding the spectral emission behavior of Earth surface materials so as to optimize the interpretation of TIMS data.

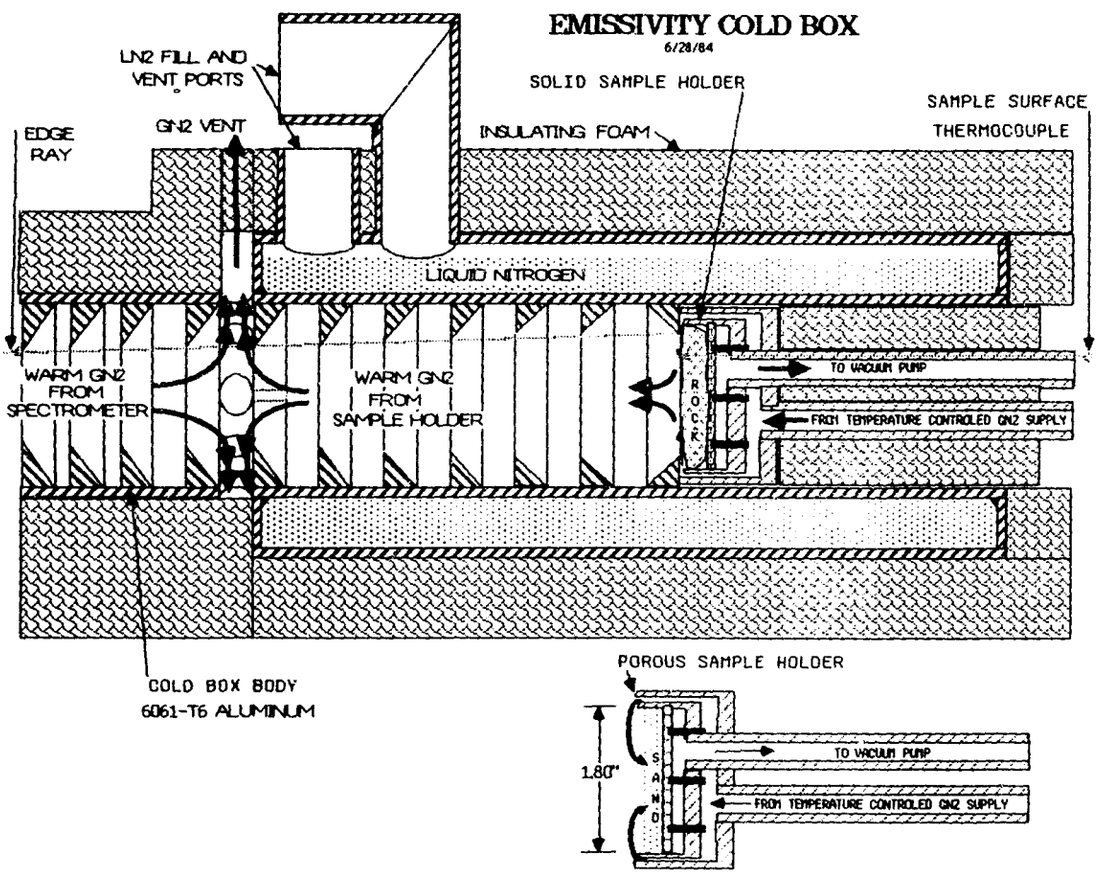


FIGURE 1. DETAILS OF EMISSIVITY COLD BOX AND SAMPLE HOLDER. GN2 = GASEOUS NITROGEN, LN2 = LIQUID NITROGEN.

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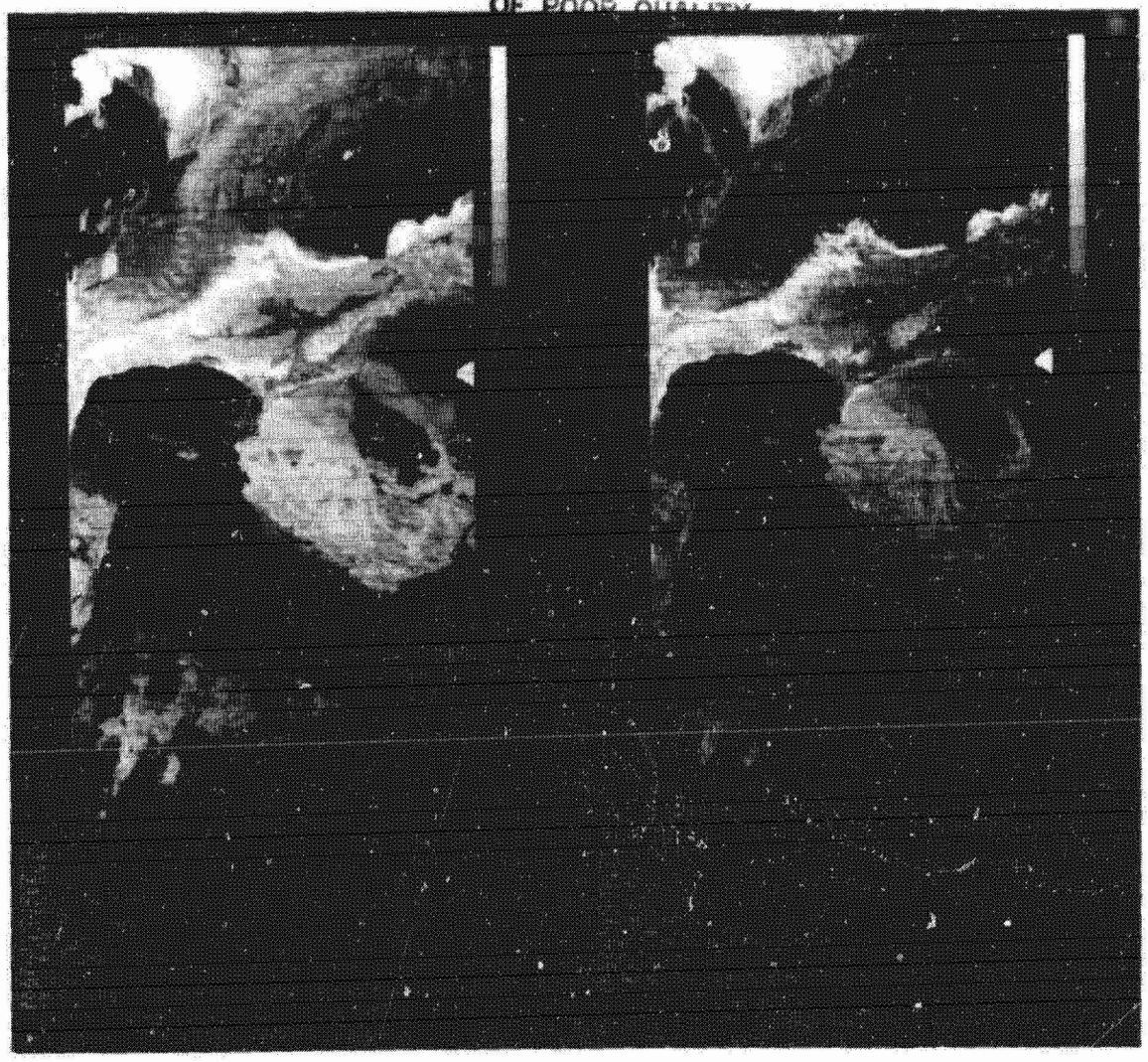

FIGURE 2. VARIATION IN GROUND SURFACE EMITTANCE IN DEATH VALLEY, CALIFORNIA, AS DETERMINED FROM CALIBRATED TIMS DATA AND PLANK'S LAW. IMAGE 2A WAS DERIVED FROM CHANNEL 3 DATA (WAVELENGTH RANGE = 9.0-9.4 MICROMETERS) AND 2B COMES FROM CHANNEL 4 DATA (WAVELENGTH RANGE = 9.6-10.2 MICROMETERS). THE IMAGE AREA INCLUDES PART OF THE FUNERAL MOUNTAINS (TOP), VALLEY FLOOR (CENTER) AND PART OF THE PANAMINT MOUNTAINS (BOTTOM).

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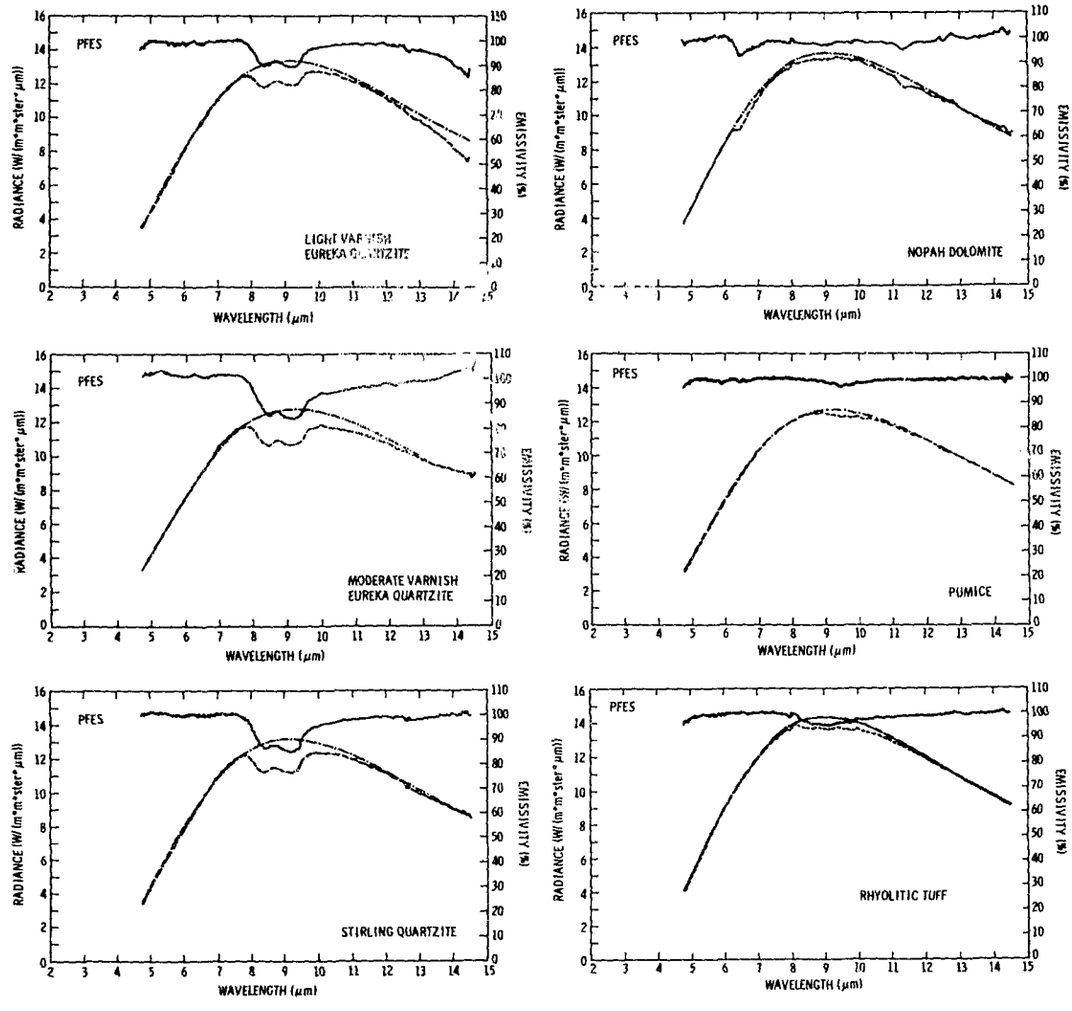

FIGURE 3. NORMAL SPECTRAL RADIANCE AND SPECTRAL EMITTANCE OF ROCKS FROM DEATH VALLEY, CALIFORNIA, AS DETERMINED BY THE PFES.

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N86-13803

ATMOSPHERIC AND SCENE COMPLEXITY EFFECTS ON SURFACE BIDIRECTIONAL REFLECTANCE

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1. Justification and Objectives

Among the tools used in passive remote sensing of Earth resources in the visible and near-infrared spectral regions are measurements of spectral signature and bidirectional reflectance functions (BDRFs). Determination of surface properties using these observables is complicated by a number of factors, including (a) mixing of surface components, such as soil and vegetation, (b) multiple reflections of radiation due to complex geometry, such as in crop canopies, and (c) atmospheric effects. Differences in surface conditions, spectral coverage, viewing and illumination geometry, and atmospheric conditions make comparison of observations obtained in the laboratory, in the field, and from aircraft and spacecraft extremely difficult. In order to bridge the diversity in these different approaches, there is a need for a fundamental physical understanding of the influence of the various effects and a quantitative measure of their relative importance. In particular, we consider scene complexity effects using the example of reflection by vegetative surfaces. The interaction of sunlight with a crop canopy and interpretation of the spectral and angular dependence of the emergent radiation is basically a multidimensional radiative transfer problem. In the first step of the radiation history, sunlight is directly and diffusely transmitted downward through the Earth's atmosphere. The downward radiation field then interacts with the plant canopy. Each element of the canopy (leaves, stems) reflects (and transmits) light according to its intrinsic bidirectional reflectance (and transmittance) properties. The complex canopy geometry, underlying soil cover, and presence of diffuse as well as collimated illumination will modify the reflectance characteristics of the canopy relative to those of the individual elements. Finally, upwelling radiation emergent from the canopy will be directly and diffusely transmitted by the atmosphere to space, and some contamination of the spectral signature with radiation reflected from neighboring surface regions will occur due to scattering associated with the adjacency effect. The intent of this research program is to develop some of the tools needed in order to achieve a quantitative understanding of such phenomena, using a combination of experimental and theoretical methods.

2. Technical Approach

The tools which are needed in order to study this radiative transfer problem include (a) knowledge of the bidirectional scattering properties of individual canopy elements, primarily leaves, as well as of the canopy as a whole, (b) a model describing the interaction of radiation with the canopy, and (c) a radiative transfer algorithm for describing the interaction of a nonuniform radiation field with the atmosphere. In order to obtain realistic leaf bidirectional reflectance functions for incorporation into canopy and scene models, we are using laboratory spectrogoniometry to study the intrinsic scattering properties of individual leaves. These measurements provide a data set which obviates the need for nonphysical model assumptions, such as Lambertian leaf BDRFs. We have been using a goniometer located

at the University of California, Los Angeles to obtain spectra of individual leaves for a variety of illumination and viewing geometries. The instrument operates in the spectral range 0.4 to 2.5 μm. The illuminating source may be placed at an inclination of 0 to 90° relative to the surface normal and essentially the entire range of emission and azimuth angles may be measured, including near-zero, grazing, and high phase angles. An important attribute is the ability obtain data out o. the principal plane of scattering. The leaf BDRFs obtained in this manner will be made available to other researchers for incorporation into canopy models. With regard to atmospheric effects, including extinction (absorption and scattering); addition of path radiance; multiple reflections between atmosphere and ground; and adjacency effects (whereby radiation reflected from surface regions not in the field of view are scattered into the line of sight), we have been developing comprehensive computational tools for solving multidimensional radiative transfer problems. Our technique incorporates a two dimensional spatial Fourier transform of the radiative transfer equation, and the resulting expressions for each Fourier component of the radiation field are computed. The full 3-D intensity field is then reconstructed using the inverse Fourier transform. The mathematical description is of general form so as to include consideration of non-Lambertian BDRFs. Our technique has been specifically designed to overcome some of the approximations employed in previous methods and has been implemented on a minicomputer. The method is nearly as general as Monte Carlo but has the advantage of providing deterministic solutions for the upwelling and downwelling radiations fields at many altitudes, zenith angles, and azimuths from a single computer run.

3. Research Results

Experimental data have been acquired using the UCLA goniometer on camellia, cucumber, and cauliflower leaves. In order to monitor the effect of using cut leaves versus leaves still attached to the plant, the reflectance of a cucumber leaf was monitored for several hours following clipping. Reflectivity at 0.98 μm increased during this period, indicating water stress and a decrease in the strength of the water band. To study spectral dependence of leaf BDRF, we obtained spectra of a camellia leaf at view angles of 0 and 30 degrees for illumination at normal incidence. The ratio of these spectra in the 0.4 - 0.9 μm region is displayed in Fig. 1. The increased noise level at the short wavelength end is due to lower detector response and decreased source light levels. This plot shows that the leaf BDRF deviates markedly from Lambertian behavior in a spectrally dependent fashion. The greatest departure from Lambertian reflectance is observed in the 0.68 μm chlorophyll absorption feature, possibly as a result of a decrease in the amount of multiple scattering within the leaf.

As an example of the success of our multidimensional radiative transfer algorithm, we consider the albedo step function problem, in which two semi-infinite fields of differing albedo are adjacent to one another. This model is useful in that it provides (a) an evaluation of the diffusion of radiation across the sharp albedo boundary separating the two regions, and (b) the ability to verify that the solution asymptotically approaches the correct result for a homogeneous surface at large distances from the boundary. This surface model may be considered to represent a coastal boundary, in which a large expanse of low albedo water borders a broad land area of higher reflectivity. We compare results obtained using the Fourier transform method with Monte Carlo results for an atmospheric model consisting of a clear atmosphere with a scale height of 8 km and an optical depth of 0.189, corresponding to Rayleigh scattering at 0.47 μm. The two half-planes are Lambertian with albedos of 0.0 and 0.6, and the solar zenith angle is 40°. This set of condi-

tions is referred to as Model 1. Figure 2 shows the results of calculations for Model 1 using the Fourier transform technique, along with selected points from the Monte Carlo results. The total upwelling intensities are shown as the sum of the diffuse (multiply scattered) radiation field and the direct field, which consists of photons transmitted to space without being scattered. The agreement between the two methods appears to be excellent. We also show at large distances from the boundary the intensities calculated using the one-dimensional matrix operator method for uniform albedos of 0.0 and 0.6, demonstrating that the Fourier transform results approach the expected values away from the boundary. In the vicinity of the boundary, the adjacency effect is apparent. Due to scattering within the atmosphere, the upwelling intensities on either side of boundary are affected by photons reflected from the surface on the opposite side of the boundary and then scattered into the line of sight. In effect, the atmosphere "blurs" the boundary with a point spread function whose width is a few kilometers. The Fourier transform technique is useful in that its underlying mathematical formalism demonstrates how the atmosphere filters high spatial frequency information from the upwelling radiation field. This filtering can be described by the computation of atmospheric modulation transfer functions (MTFs). Figure 3 is a comparison of MTFs calculated using our technique for a Rayleigh atmosphere and an aerosol laden (hazy) atmosphere, each of total optical depth 0.3 and 5 km scale height. These MTFs indicate that the more highly forward scattering haze phase function results in a greater observability of the adjacency effect.

Another area in which the 3-D radiative transfer algorithm is proving useful is in the development of a technique for determining atmospheric transmittance from surface images acquired at off-nadir view angles. The basis of the method is as follows: As shown in Fig. 2, the total upwelling radiance is the sum of a direct and diffuse component. Radiation directly transmitted to space is proportional to the surface albedo distribution, and a sharp discontinuity in the surface albedo gives rise to a similar discontinuity in the direct field. The diffuse field, on the other hand, while exhibiting a qualitative similarity to large scale variations in surface albedo, exhibits a much smoother character, owing to the filtering effects of the atmosphere, as discussed above. The direct field, which is also proportional to atmospheric transmittance $\exp(-\tau/\mu)$, where τ is the optical depth and μ is the cosine of the view angle, thus has a very different spatial character from the diffuse field. If we compute the spatial Fourier transform of upwelling radiances within an image, the spatial "smoothness" of the diffuse field means that it will make a negligible contribution at high spatial frequencies. Thus, if we eliminate low frequency Fourier components we are left with a measurement that is directly proportional to the atmospheric transmission factor $\exp(-\tau/\mu)$. By obtaining images of the same surface region at several view angles, it should in principle be possible to solve for τ, provided non-Lambertian surface effects can be minimized. Our calculations suggest that acquisition of images in the vicinity of 60° off-nadir should be sufficient to accomplish this and recover atmospheric transmittance with an accuracy of 5-10%.

4. Significance of Results and Future Directions

Many investigators have studied the spectral properties of a wide variety of crop samples. The spectral reflectance of the foliage is modified by changes in the internal structure of the leaves associated with various forms of stress, such as water or mineral stress. The specularity of the reflected radiation increases at wavelengths where increased absorption occurs, presumably due to reduced depth of penetration of the incident radiation into the leaf resulting in fewer multiple

reflections between layers. Therefore, we expect changes in leaf structure resulting from stress to affect the angular as well as spectral reflectance properties. Thus, it is important to incorporate realistic (non-Lambertian) leaf bidirectional reflectance functions into canopy and scene models. The spectrogoniometric leaf measurements will provide such data.

The Fourier transform radiative transfer algorithm which we have developed is a useful tool for studying the effect of the atmosphere on high spatial resolution imaging of the Earth's surface. As discussed above, the sharpness of the adjacency effect in the vicinity of albedo boundaries is dependent upon the vertical distribution of the atmospheric scatterers. We are using our radiative transfer method to perform a systematic study of the variation of atmospheric point spread functions with aerosol vertical distribution, phase function, single scattering albedo, and optical thickness. The results of such calculations will permit evaluation of the possibility of observing atmospheric blur directly in high resolution images of the Earth's surface, with the goal of determining aerosol properties. Conversely, these calculations will lead to techniques for removing spectral contamination associated with the adjacency effect.

Further work is necessary in order to demonstrate the feasibility of implementing the multiple view angle optical depth retrieval technique on a space platform. The major uncertainty at present is the manner in which the unknown angular reflectance properties of the surface should be taken into account. For the model BDRF we used in our simulations, off-nadir imaging near 60° appears appropriate to compensate for lack of a priori knowledge of the shape of the surface BDRF. Whether this range is appropriate for natural surfaces can only be determined by experimentation in the field. A number of portable field spectrometers are available for obtaining BDRF measurements. The success of this technique would be significant because it provides a means of monitoring tropospheric opacity, which is important not only for atmospheric studies but also because it is one of the most important parameters governing the effect of the atmosphere on surface images. An extension of the optical depth retrieval technique is to near infrared spectral regions where water vapor absorption occurs. In its current form, the technique relies on the assumption that atmospheric transmittance variesias $\exp(-\tau/\mu)$. In the water vapor bands, any finite bandwidth spectral channel will incorporate many individual lines and this law may not be followed. In order to study the view angle dependence of transmittance in such regions, we are developing a radiative transfer algorithm which permits calculation of broadband radiances for channels containing many absorption lines in the presence of aerosol scattering.

Finally, we plan to investigate the applicability of our 3-D radiative transfer method to scattering in plant canopies. In principle, our algorithm is applicable to heterogeneous media and has the advantage of providing a true solution to the multidimensional radiative transfer equation. In addition, solutions are obtained at many view and illumination angles and azimuths, thus providing the full canopy BDRF. Variation of the BDRF of the individual leaves will permit study of the effect of changing reflectance properties of the individual canopy elements on the canopy angular and spectral reflectance as a whole. Such calculations will mesh nicely with the goals of the experimental portion of this investigation.

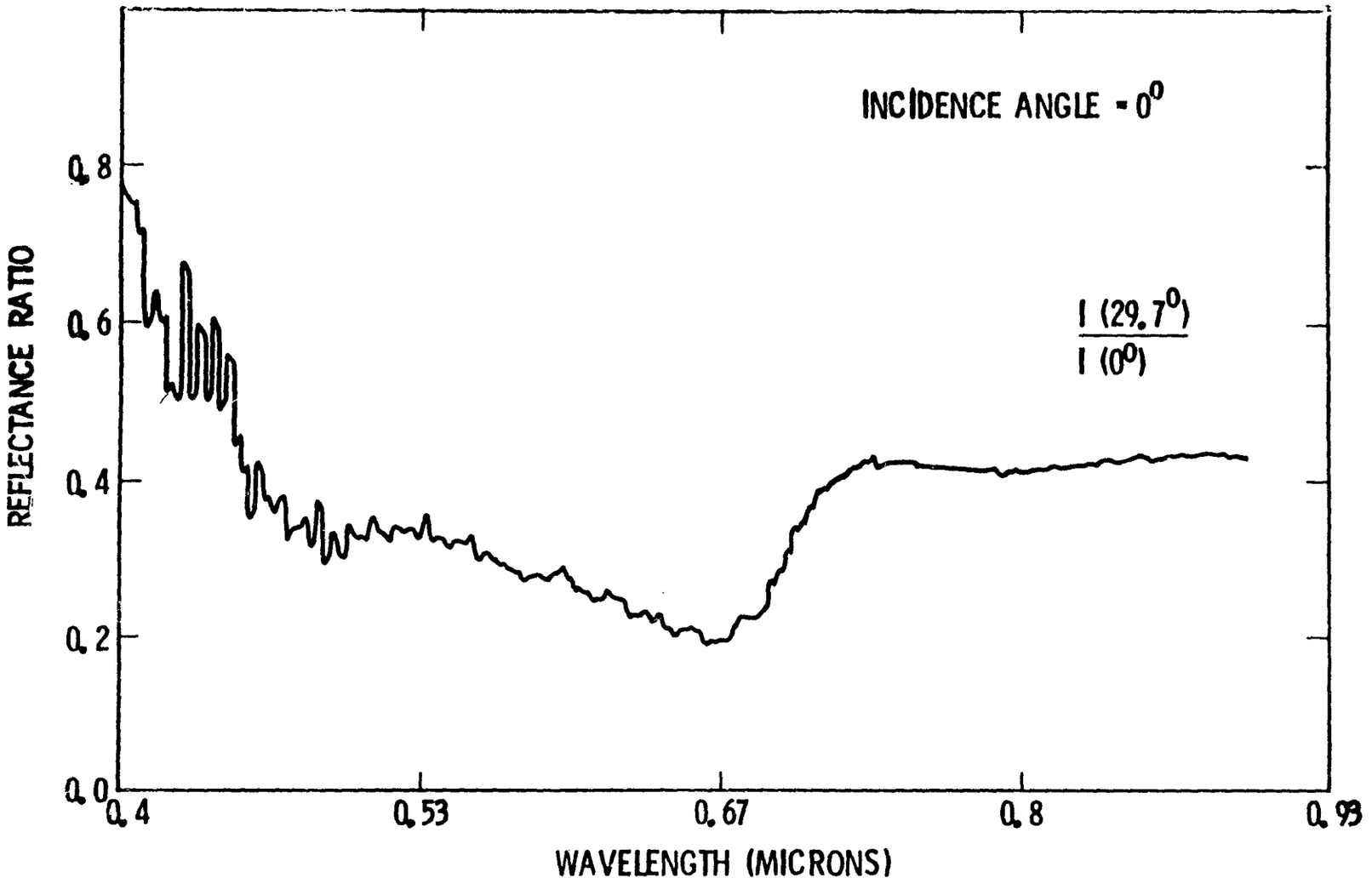

Fig. 1. Ratio of reflected intensity at 30° view angle to 0° view angle for camellia leaf.

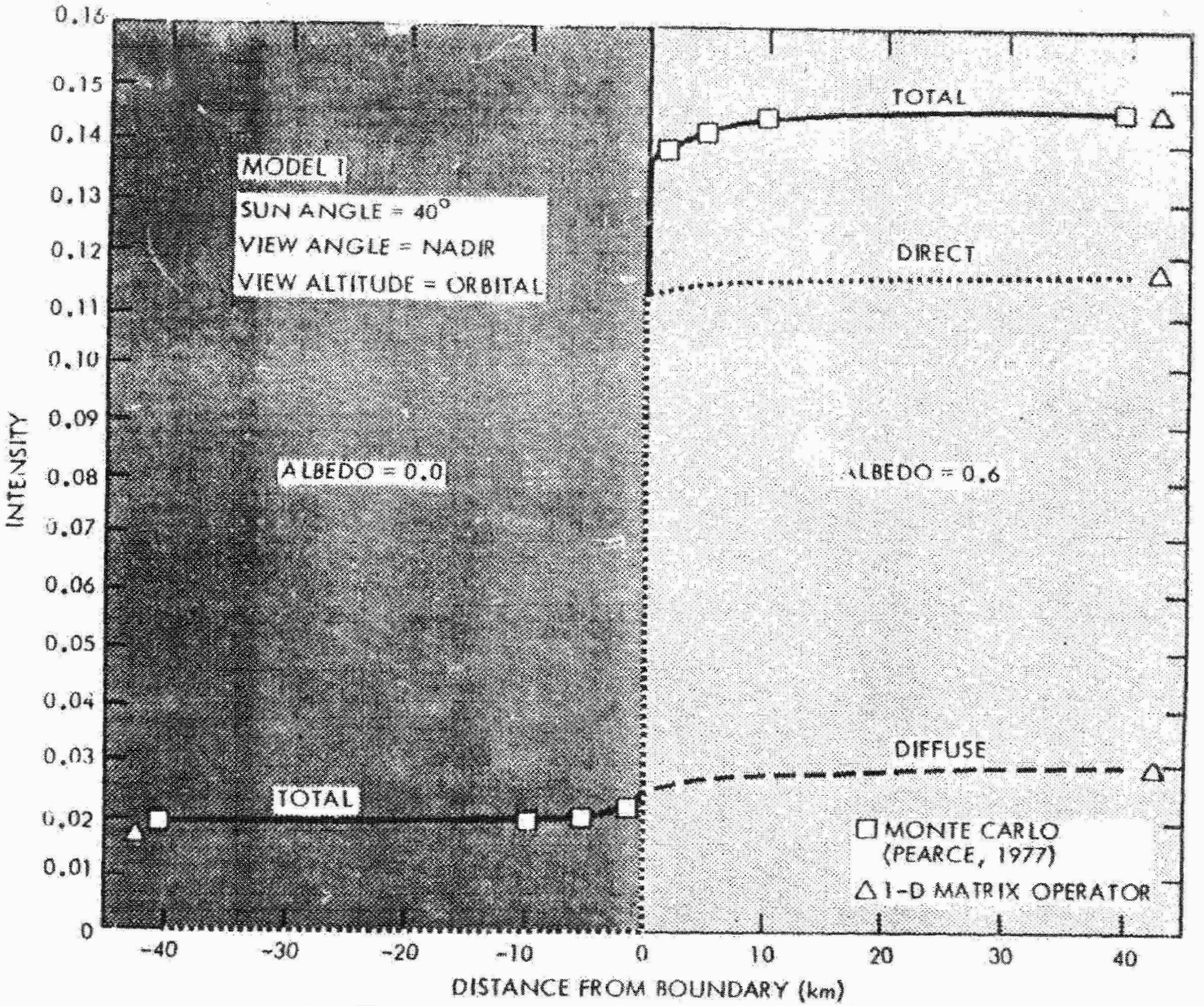

Fig. 2. Upwelling intensity in vicinity of albedo discontinuity for Model 1.

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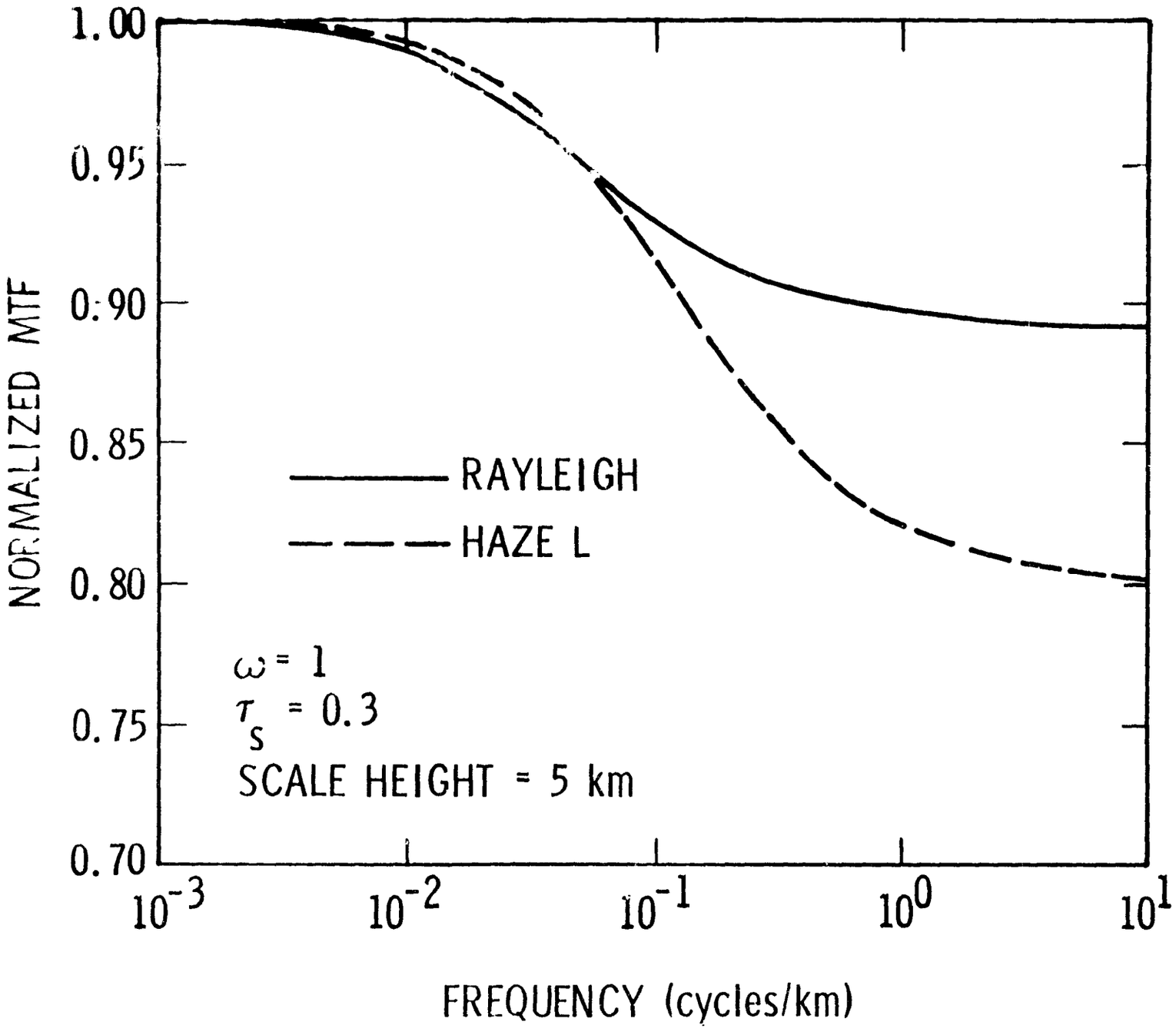
1.00
0.95
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0.70
NORMALIZED MTF
RAYLEIGH
HAZE L
ω = 1
τs = 0.3
SCALE HEIGHT = 5 km
10-3
10-2
10-1
100
101
FREQUENCY (cycles/km)

N86-13804

ATMOSPHERIC EFFECT ON REMOTE SENSING OF THE EARTH'S SURFACE

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1. INTRODUCTION

The Earth's atmosphere has a significant bearing on the quality of images of the Earth's surface as observed from space by reflected sunlight. This atmospheric effect is caused by absorption and scattering of sunlight by molecules and aerosols. The molecular effects can be accounted for, but the aerosol effects are variable and poorly known during satellite observations. The optical parameters used to compute the atmospheric effects are: its optical depth to determine the extinction of light; the single scattering albedo, which is the fraction of light scattered from total extinction; and the scattering phase function giving the probability of scattering in a particular direction.

The atmosphere tends to make dark surfaces appear brighter and bright surfaces darker, but the resultant effect depends on the surface reflectance pattern itself. Atmospheric scattering diffuses the boundaries between adjacent fields. This effect, called the adjacency effect, is due to light reflected from the ground surrounding a sensor's field-of-view and then scattered into the field-of-view. The adjacency effect depends on the above mentioned optical parameters and on the depth of the aerosol layer.

Theoretical analyses of atmospheric effects, ground-based measurements of atmospheric parameters, and analysis of satellite data are reported on here. This work occurred during the period 1982-4.

2. JUSTIFICATION, OBJECTIVES, AND APPROACH

2.1. Justification

Recently developed theoretical models of radiative transfer in the atmosphere can be used to perform atmospheric corrections for known aerosol characteristics. The development of correction algorithms requires testing the models against measurements to investigate the main atmospheric characteristics that affect certain remote sensing techniques, and to develop methods to measure these characteristics from ground and from space.

2.2. Objectives

To study the atmospheric effect on remote sensing by theoretical modeling and to measure this effect. To relate the effects of the atmosphere to the aerosol characteristics in order to determine which are the main characteristics that affect a given remote sensing function. The specific goals are:

a. Laboratory simulation and analysis of field measurement of the atmospheric effect to study the effect and to validate theoretical models.

b. Development of a theoretical model that can simulate the atmospheric effect over any variable surface.

c. Study the atmospheric effect on the spatial resolution of satellite images of the surface and on classification of surface features.

d. Analyze the relative importance of aerosol scattering and absorption on remote sensing of the surface in order to determine if atmospheric corrections based on the optical thickness alone are feasible.

e. To measure the atmospheric characteristics that are important for atmospheric corrections: optical thickness, path radiance, scattering phase function, and single scattering albedo, and find the relations between them in order to establish the minimum information required for atmospheric corrections.

2.3 Approach

a. In order to measure the atmospheric effect and test theoretical models, a field and controlled laboratory experiments are performed in the presence of nonuniform surface reflectance.

b. The simulation of the atmospheric effect over a general varying surface reflectance is performed by the calculation of the atmospheric Modulation Transfer Function (MTF) and application of two-dimensional Fourier Transforms for the calculation.

c. Analyze the aerosol effect on spatial reduction and classification by means of the atmospheric MTF and application of the 2-D Fourier Transform technique.

d. Radiative transfer computations are used to derive the relative importance of aerosol scattering and absorption on remote sensing of the surface albedo, vegetation index, and classification.

e. A system is developed to measure simultaneously from the ground the optical thickness, the path radiance, the scattering phase function, and the single scattering albedo. The covariance between these parameters is studied. Inversion procedures are developed to derive from the observations the aerosol optical-thickness, scattering phase function, and absorption.

3. RESEARCH RESULTS

3.1. Measurement of the atmospheric effect

A laboratory experiment [6] was conducted in which a half white, half black plate represented the nonuniform surface and a dish with hydrosol of latex spheres represented the hazy atmosphere. A solar simulator irradiated the dish and a detector scanned the upward radiance across a line perpendicular to the border between the white and black area. Fig. 1A shows an example of the measured radiance and the theoretical fit [1] as a function of the distance from the boundary X (normalized by the hydrosol height H). In this experiment the adjacency effect (the effect of a bright object on the radiance above a nearby dark object) was measured as a function of hydrosol optical thicknesses for nadir and off nadir observation directions. Good agreement was found between theory and experiment. The measured adjacency effect had an amplitude 20% higher than the theoretical one, and a range 25% shorter than in theory.

A field experiment was also conducted [8] in which the upward radiance above and below the haze layer was measured simultaneously with ground and airborne measurements of the atmospheric characteristics. Fig. 1B shows an example of the upward radiance from the nadir below and above the base. The radiances are measured over the dark water as a function of the distance from the bright vegetated land (the wavelength is 773 nm). The reflectance of the vegetated surface was approximately 0.35. A comparison with theory shows similar good agreement as in the laboratory study, with the adjacency effect somewhat stronger and narrower than in theory (as was found in the laboratory study). This difference can be due to the approximations in the theory and due to errors in accounting for very large particles.

3.2. Resolution and classification

The experimental verification of the radiative transfer theory and the application of Fourier Transform [7] to generalize the theory so that the upward radiance can be simulated for any 2-D varying surface, enables the application of the theory to study the atmospheric effect on spatial resolution and classification of surface features [3], [5] and [7]. It was found (see Fig. 1C) that the atmospheric effect reduces the spatial resolution substantially. For the Thematic Mapper (TM) the spatial resolution of 30m (defined for Modulation transfer value of 0.35) is reduced to 100m by a hazy atmosphere (aerosol optical thickness = 0.5, λ = 550nm). An atmospheric correction that ignores the adjacency effect can correct the resolution to 50m. Similarly, significant effects were found on classification of surface features [3] and on separability between field classes [7].

3.3 Scattering versus absorption

A theoretical study was conducted [9, 12] to test the common hypothesis that the atmospheric effect depends mainly on one atmospheric parameter—the optical thickness (τ_A). An increase in the amount of aerosol tends to brighten dark surfaces and darken bright surfaces (see Fig. 2A). In the brightening process aerosol scattering has a dominant effect and absorption is of secondary importance; but in the darkening process the absorption has an important role. For a given bright surface the atmospheric effect can be of brightening or darkening depending on the ratio of aerosol scattering and extinction optical thicknesses (ω_0). A reliable estimate of such effects can not be made until more is known about atmospheric absorption and its variability. However, Fig. 2B shows that remote sensing of contrast such as vegetation index is weakly affected by absorption, but still affected by changes in the optical thickness. The vegetation index is a function of the slope of a line in this figure and thus does not change appreciably with absorption (from model 1 to 2 and from model 3 to 4). Figure 2B also shows how the reflectance of the earth-atmosphere system is altered by the atmosphere.

3.4 Ground-based experiment

In order to learn about the optical characteristics of the atmopshere as they affect remote sensing, a ground experiment is being performed in order to collect and analyze a substantial data base. Simultaneous measurements in the visible and near infrared spectrum are made of the solar transmission, the sky radiance in the direction of the North Star and also in the almucantar through the sun and the degree of polarization of the skylight. The aerosol optical thickness is derived from the solar transmission. The path radiance is measured in the direction of the North Star in order to minimize geometric effects and observe changes associated with aerosols. During a day the angle between the observer, sun, and North Star is essentially constant.

Attempts have been made to relate atmospheric corrections to only one parameter—namely the aerosol optical thickness, in only one spectral band. Figure 3A shows the strong correlation between path radiance (at 870nm) and optical thickness (at 610nm). 94 percent of the radiance variance is associated with optical thickness variance for these wavelengths. The correlation between the radiance at 870nm and the optical thickness at 610nm was bigger than the correlation with optical thickness at 870nm. This is due to a different size dependence of the radiance and the optical thickness. The correlation between path radiances in two spectral bands (Fig. 3B) shows the accuracy of estimating the path radiance in one band from that in another band. The radiance at 870nm can explain 74 percent of the radiance variance at 480nm and 62 percent of the radiance variance at 1670nm.

The aerosol scattering phase function is derived from the radiance of the skylight in the solar almucantar. The inversion proceeds by an iterative method to account for molecular and multiple scattering. An inversion of radiances computed for a model atmosphere is shown in Fig. 3C. The true aerosol phase function of scattering angle is given by P_4. P would be the estimated phase function derived from the radiance, if only molecular scattering was accounted for. P_0 is the first guess of the aerosol phase function, which is used to estimate the radiance of multiple scattering. This value is subtracted from the measured value to obtain the P_1-estimate of the aerosol phase function. The procedure is repeated with this new value of the phase function (P_1). After two more such iterations, the curve P_3 is obtained, and it is nearly identical to the true value (P_4). Although the simulated radiances are free of errors, an analysis of the error budget has been made. This inversion method has been applied to measured radiances. Eventually, these functions will be compared with those derived from solar transmission data.

5. CONCLUSION

Radiative transfer theory (RT) for an atmosphere with a nonuniform surface is the basis for understanding and correcting for the atmospheric effect on remote sensing of surface properties. In the present work the theory was generalized and tested successfully against laboratory and field measurements. There is still a need to generalize the RT approximation for off-nadir directions and to take into account anisotropic reflectance at the surface.

The adjacency effect results in a significant modification of spectral signatures of the surface, and therefore results in modification of classifications, of separability of field classes, and of spatial resolution. For example, the 30m resolution of the Thematic Mapper is reduced to 100m by a hazy atmosphere. The adjacency effect depends on several optical parameters of aerosols: optical thickness, depth of aerosol layer, scattering phase function, and absorption. Remote sensing in general depends on these parameter, not just adjacency effects, but they are not known well enough for making accurate atmospheric corrections. It is important to establish methods for estimating these parameters in order to develop correction methods for atmospheric effects. Such estimations can be based on climatological data, which are not available yet, correlations between the optical parameters and meteorological data, and the same satellite measurements of radiances that are used for estimating surface properties. Our knowledge about the atmospheric parameters important for remote sensing is being enlarged with current measurements of them.

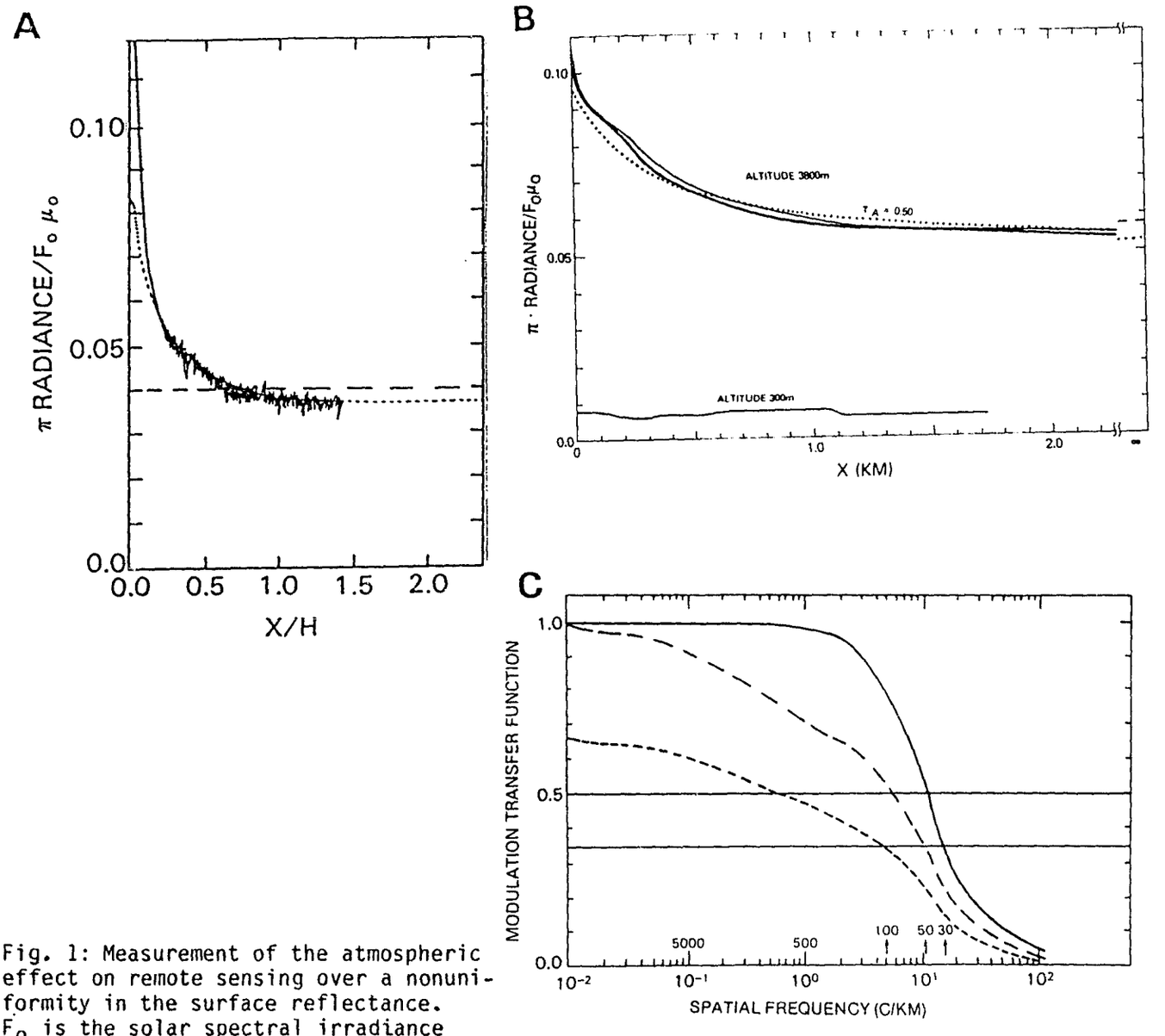
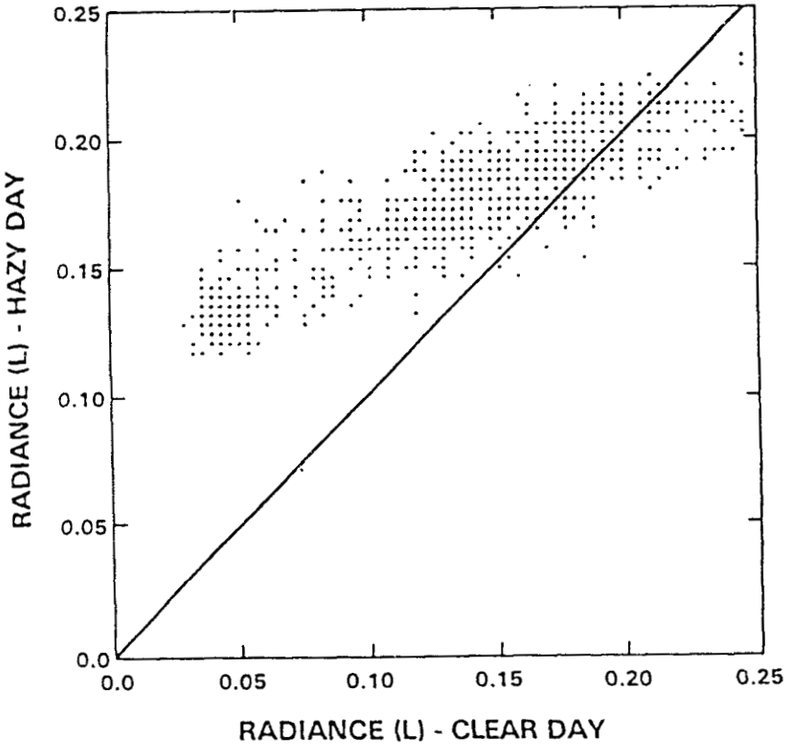
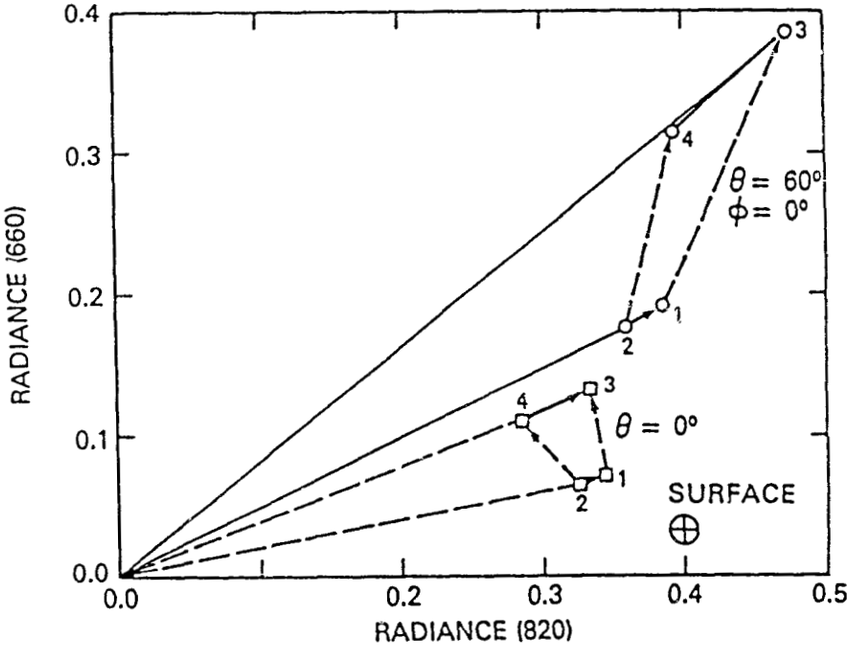


Fig. 1: Measurement of the atmospheric effect on remote sensing over a nonuniformity in the surface reflectance. F_0 is the solar spectral irradiance and θ_0=arccosine(μ_0), the solar zenith angle.
A - Laboratory simulation for optical thickness 0.3, nadir observation. The theoretical fit (....) and the surface reflectance (- - -) are indicated. X is the distance from the bright area and H the hight of the scattering medium.
B - Field measurements for aerosol optical thickness 0.5. The aircraft measurements (——) and theory (....) are indicated.
C - The atmospheric effect on spatial resolution of the Landsat Thematic Mapper (TM). The modulation transfer functions for the TM(——) alone, with atmospheric effect (....) and with correction that ignores the adjacency effect (- - -) are shown. The original resolution (30m) is reduced to 50m by the adjacency effect and to 100m by the total atmospheric effect.



A



B

Fig. 2: A - Scatter diagram of the radiance from a Landsat Image on a hazy day as a function of the radiance on a clear day taken over Washington, DC; for 700-800nm band. The radiance is normalized to reflectance units.

B - Radiance of models of the earth-atmosphere system. The surface consists of dense alfalfa. The solar zenith angle is 50°; the direction of observation is given by the polar angle θ, and azimuth ϕ from the direction of propagation of incident sunlight. The number besides the plotted points refer to the aerosol models:

MODEL	ω_0	τ_A(660nm)	τ_A(820nm)
1	0.96	0.287	0.200
2	0.88	0.287	0.200
3	0.96	0.861	0.600
4	0.88	0.861	0.600

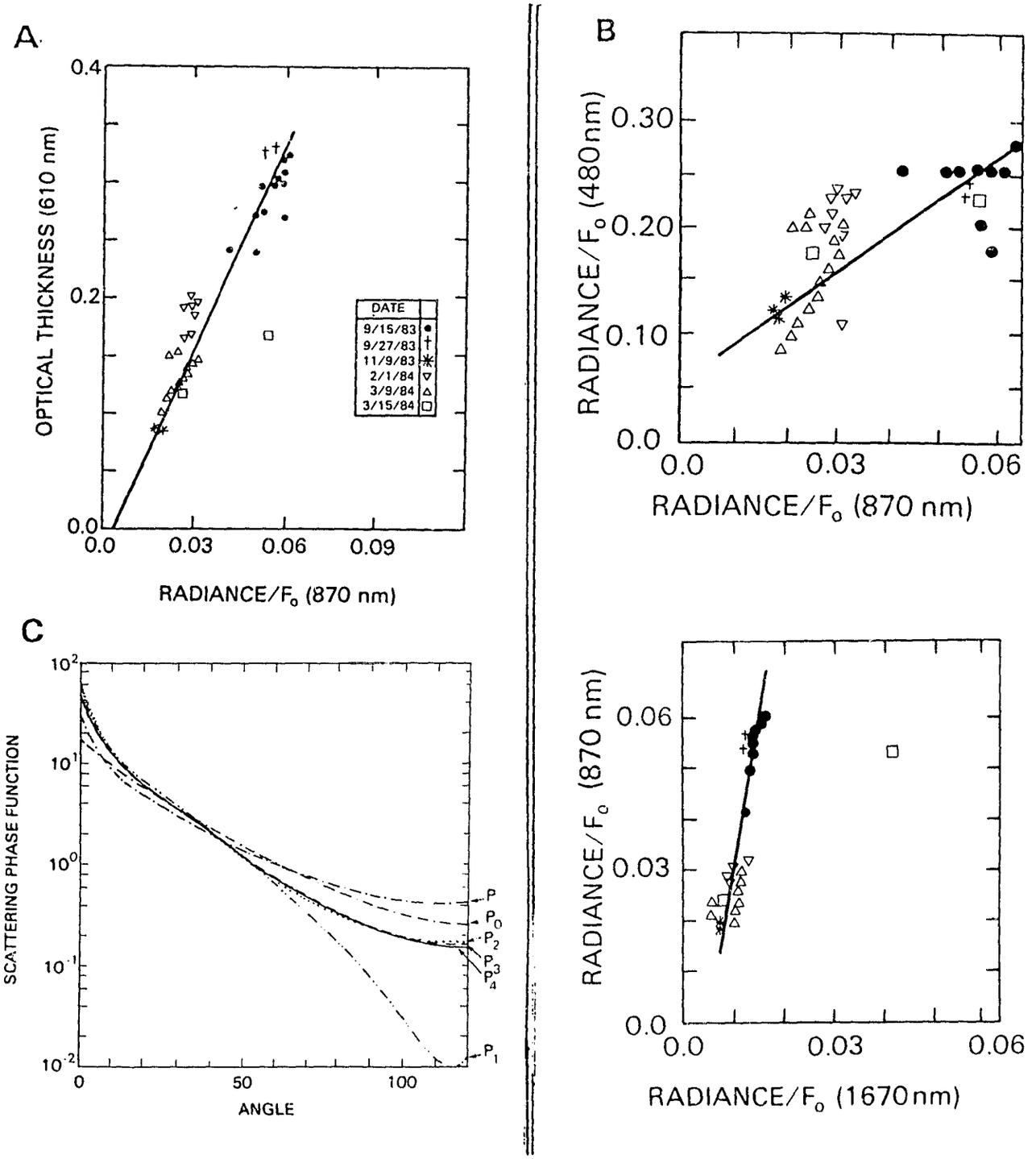


Fig. 3: Example of analysis of ground measurements of the sky radiance.
A - The relation between the optical thickness τ_a at(610nm) and the sky radiance (at 870nm) in the direction of the North star. Each symbol represents a different observation day.
B - The correlation between the sky radiance at 480nm and 870nm; and 870nm and 1670nm.
C An example of inversion of the almucantar simulated radiances for the aerosol scattering phase function.

N86-13805

THE CHARACTERIZATION OF SURFACE VARIEGATION EFFECTS ON REMOTE SENSING

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Improvements in remote sensing capabilities hinge very directly upon attaining an understanding of the physical processes contributing to the measurements. In order to devise new measurement strategies and to learn better techniques for processing remotely gathered data, we need to understand and to characterize the complex radiative interactions of the atmosphere-surface system. In particular, it is important to understand the role of atmospheric structure, ground reflectance inhomogeneity and ground bidirectional reflectance type. Our goals, then, are to model, analyze, and parameterize the observable effects of three dimensional atmospheric structure and composition and two dimensional variations in ground albedo and bidirectional reflectance.

To achieve these goals, we employ a Monte Carlo radiative transfer code to model and analyze the effects of many of the complications which are present in nature. We can, for example, treat finite clouds as well as vertical atmospheric structure. We can model the effects of two dimensional structure in ground albedo and directional reflectance. We can examine alternate data acquisition strategies perhaps involving variations in detector viewing direction, solar illumination direction, or polarization sensitivity. Most importantly, for the purposes of analysis and characterization, we can divide the detected radiance into components. The radiance transmitted directly through the atmosphere from the ground to the detector is the

component which carries the most significant information about the character of the surface. The radiance arising solely from atmospheric scattering is a term which, in effect, should be subtracted from the data as it has no bearing on the surface character. Lastly, there is a ground diffuse component comprised of radiation which, having scattered from the ground, is atmospherically scattered prior to detection. This last term is responsible for non-local adjacency effects. Its influence on the data usually may be described by an atmospheric spread function.

Specifically, the objectives of the present study are to investigate the sensitivity of the radiance components and the atmospheric spread function to: variations in the vertical aerosol profile; variations in the aerosol size distribution (and, hence, its scattering distribution); variations in the detector look direction and solar illumination direction; variations in ground reflectance type and bidirectional reflectivity; the presence of clouds in the vicinity of the point of view.

RESULTS

As the modal radius of the atmospheric aerosol size distribution increases, the associated scattering phase function is enhanced both in the forward and backward directions. For remote sensing, it is the changes in the forward scattering peak which are more important. Our simulations show significant sensitivity in the inner regions of the spread function (within 250 meters of the point of view). Figure 1 illustrates this, showing the atmospheric modulation transfer function, or MTF (the Fourier transform of the atmospheric line spread function) for three log-normal size distributions with modal radii of 0.13, 0.26, and 1.04 micrometers (bottom curve, middle curve, and top curve, respectively).

For Lambertian ground reflectance, there is relatively little sensitivity to detector nadir angle for nadir angles less than about 40 degrees. For larger nadir angles, however, the atmospheric line spread function becomes asymmetric and depends upon the illumination angle. Figure 2 shows the atmospheric line spread function for a detector nadir angle of 50 degrees (detector pointing roughly into the sun), while the dashed curve is for 180 degree receiver azimuth. The solar zenith angle for both cases is 47 degrees. The line spread function here is computed from the gradient of the intensity in a scan across a fixed albedo boundary. The asymmetry is due primarily to the forward-backward asymmetry of the aerosol scattering phase function.

Variations in the form of the vertical aerosol density profile tend to scale the range of the atmospheric spread function. This scaling appears to be roughly linear in the average aerosol altitude.

Clouds in the vicinity of the point of view can influence the detected radiance. In particular, the shadow of a cloud produces much the same intensity gradient when scanning across its edge as is obtained for a high contrast ground albedo boundary. Figure 3 shows a detailed comparison of the radiance components for two cases. The solid lines show (from top to bottom on the right side of the figure) total radiance, ground direct radiance and atmospheric radiance as detected from nadir while scanning across a Lambertian albedo boundary (albedos 0.4 and 0.07). The symbols correspond to a similar scan across a cloud shadow boundary (the ground albedo is 0.4, the solar zenith angle is 47 degrees, and the altitude of the cloud top is 7 km.). The pluses indicate total radiance; the solid squares show the ground direct radiance; the open squares show the ground diffuse component; and the crosses mark the atmospheric radiance. Here, the atmospheric component varies because the cloud shades the scattering atmosphere as well as the ground. The ground direct radiance varies less abruptly on the dark side of the shadow due to cloud transparency and translucence. The

overall effect for the two cases is remarkably similar even though the components contributing to the total behave rather differently. Note that the range of the effect of the shadow on the detected intensity is significantly large.

SIGNIFICANCE AND FUTURE WORK

Our simulations have shown that the form of the aerosol scattering phase function is an important determinant of the atmospheric spread function. For nadir observation, the central peak of the spread function is primarily affected. For observations well away from nadir, the spread function can become asymmetric even though ground reflectance is Lambertian. The shape of the spread function is not very sensitive to the vertical profile of the aerosol. We have found that the shadows of high, dense clouds produce changes in the total detected radiance quite similar in range and magnitude with those associated with a high contrast ground albedo boundary. The radiance components, however, are not so similar.

The next major variable to be studied is the sensitivity of observed radiances to variations in ground bidirectional reflectance and to two-dimentional patterns of varying reflectance type. We wish especially to understand to what extent variations in bidirectional reflectance can be used to improve classification and identification of surface areas. We wish to study the utility of polarization sensitive detectors. We will extend our study of the effects of clouds, looking both at high thin clouds and at the detailed effects associated with low thick clouds.

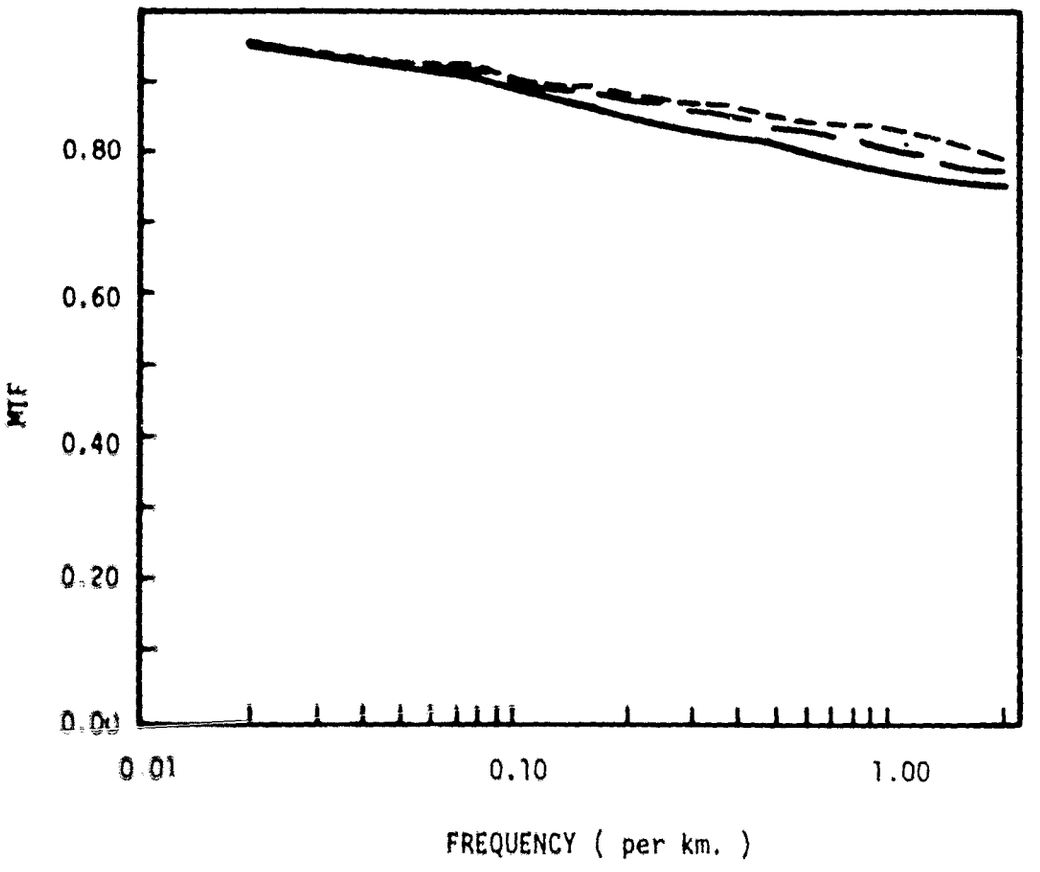


FIGURE 1.

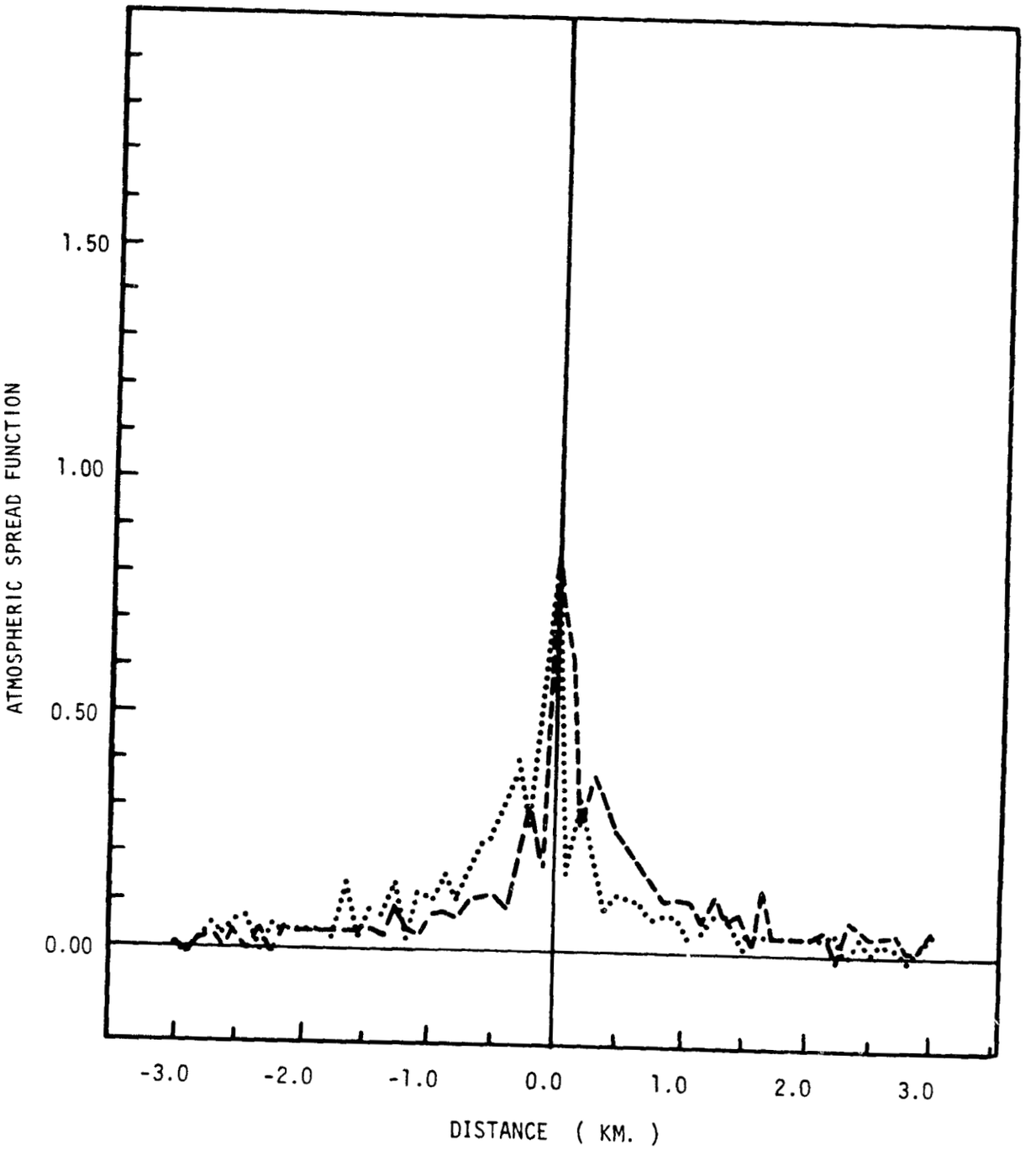
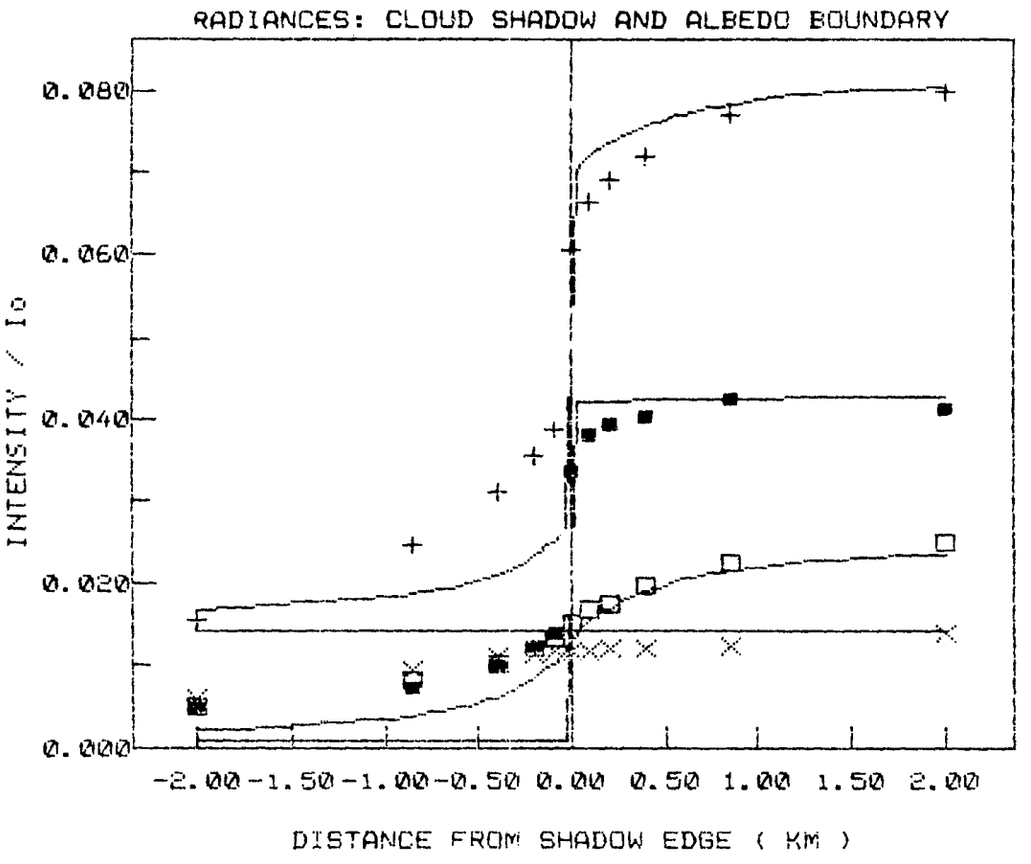

ATMOSPHERIC SPREAD FUNCTION
1.50
1.00
0.50
0.00
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
DISTANCE (KM.)

FIGURE 2.



C1 CLOUD

FIGURE 3.

N86-13806

MULTIDIMENSIONAL MODELING OF ATMOSPHERIC EFFECTS AND SURFACE HETEROGENEITIES ON REMOTE SENSING

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Theoretical Division
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The overall goal of this project is to establish a modeling capability that allows a quantitative determination of atmospheric effects on remote sensing including the effects of surface heterogeneities. This includes an improved understanding of aerosol and haze effects in connection with structural, angular, and spatial surface heterogeneities. One important objective of our research is the possible identification of intrinsic surface or canopy characteristics that might be invariant to atmospheric perturbations so that they could be used for scene identification. Conversely, an equally important objective is to find a correction algorithm for atmospheric effects in satellite-sensed surface reflectances.

Our technical approach is centered around a systematic model and code development effort based on existing, highly advanced computer codes that were originally developed for nuclear radiation shielding applications. Computational techniques for the numerical solution of the radiative transfer equation were adapted on the basis of the discrete-ordinates finite-element method which proved highly successful for one- and two-dimensional radiative transfer problems with fully resolved angular representation of the radiation field.

Results of the initial phases of our research project, namely, the implementation and verification of computer codes and modern atmospheric data bases, have been published and proved highly successful. In the next step, a coupled atmosphere/canopy model was developed that allowed us to perform a sensitivity analysis and to quantify how satellite-sensed spectral radiances are affected by increased atmospheric aerosols, by varying leaf area index, by anisotropic leaf scattering, and by non-Lambertian soil boundary conditions. Our numerical results allow the following conclusions:

1. Atmospheric perturbations are the major contributors to Landsat MSS bands 1 and 2 (visible), while they play only a minor role in MSS bands 3 and 4 (near-IR) for remotely sensed images of vegetative surfaces. The Kauth-Thomas greenness parameter is found nearly proportional to the atmospheric optical depth over uniform vegetative surfaces.

2. The inclusion of anisotropic leaf scattering characteristics in our canopy model is significant to explain reflectance measurements directly above the canopy but produces only negligible effects on satellite-measured data above the atmosphere at nadir.

3. Non-Lambertian and specular surface reflectance characteristics (BRDF) affect satellite measurements at nadir only insignificantly but can make large differences for off-nadir observations.

The details of these results are also published and led us to our most recent investigations of how typical non-Lambertian angular canopy reflectance characteristics may be used for scene identification.

Identifiers for horizontally homogeneous vegetated surfaces that may be used in remote sensing are the spectral distribution and the angular distribution of radiances above the canopy. The spectral distribution is determined by the optical properties of the constituents of the particular canopy, e.g., leaves and stems, while the angular distribution is created mainly by the canopy architecture. While the spectral characteristics of most canopy components are very similar for most plants, the canopy architecture may be most dissimilar. This fact leads to intrinsic canopy angular reflectance patterns that may be typical for certain classes of plant canopies. Thus, the atmospheric perturbations of the angular reflectance pattern of a Lambertian, a mixed Lambertian/specular surface, and of the measured BRDFs of savannah and coniferous forest canopies were studies using aerosol-free and polluted atmospheres.

Two typical results of our calculations are shown in Figs. 1 and 2, where measured angular reflectance patterns above real canopies are computationally "transported" through a mildly aerosol-loaded atmosphere to a hypothetical off-nadir satellite sensor. These results show that maxima, like the canopy "hot spot" (a dominant peak when viewing in the direction of the sun with the sun at observer's back), are still detectable above the atmosphere even if observed through heavily aerosol-loaded atmospheres. It appears that especially those patterns that vary with the azimuth angle are better preserved than variations with view zenith angles. Note, in particular, how the shape of the reflectance pattern along the 180° azimuth changes when transported through the atmosphere, while variations with the azimuth along the 30° zenith remains basically the same. The underlying cause for this effect is obviously the constant path length through the atmosphere for all directions with the same view zenith angle. Thus, strong azimuthal variations typical for any surface or canopy reflectance pattern undergo only minor perturbations by the atmosphere, while the angular patterns for varying view zenith angles are much more perturbed by atmospheric effects. This finding suggests that off-nadir satellite observations with varying view azimuth angles may contribute significant new data that is expected to be valuable for crop identification.

In our search for an effective new atmospheric correction algorithm, we are presently performing exploratory calculations with the objective of reconstructing, from radiance distributions above the atmosphere, a typical angular reflectance pattern as measured directly above a canopy. Figs. 1 and 2 demonstrate clearly the severe atmospheric perturbations that are cumulatively added to the upwelling radiance distributions, especially in the visible wavelength region and for large view zenith angles. However, we show in Fig. 3 the result of a simple correction algorithm applied to the coniferous forest data (see also Fig. 1) for an aerosol-polluted, rural atmosphere of horizontal visual range of 23 km, equivalent to vertical optical depth at 0.55 μm of 0.45

for the entire atmosphere. The top half of the iso-radiance contour plots give Kriebel's measured data directly above the forest canopy while the bottom half shows our reconstructed radiance distributions from values above the atmosphere but corrected for atmospheric perturbations. This correction is based on a simple subtraction of the atmospheric path radiance component as determined from an independent additional radiative transfer calculation assuming purely Lambertian surface reflectance but with the same albedo as that of the real canopy. For our forest canopy, we have α = 11% at 0.85 μm. The comparison in Fig. 3 shows an agreement within approximately 10% between the measured and reconstructed radiance distributions for view zenith angles lower than 60° and all view azimuth angles. The hot spot is almost perfectly retrieved after this simple atmospheric correction. These results are both surprising and encouraging, because the correction apparently works very well even at the visible wavelength where atmospheric effects dominate the canopy signal by far.

The next logical step in our research project must be a two-pronged approach. First, the analysis of our (as yet) simple atmospheric correction algorithm must be broadened and studied in depth. Secondly, our physical understanding of how certain typical canopy reflection patterns are correlated with measurable biophysical canopy parameters must also be deepened. To achieve this latter goal, we propose to build a simulated vegetative canopy structure using only artificial (non-living) structure elements for leaves, stalks, branches, etc., that provides a well-defined and fully reproducible testbed for verification and testing of instruments and theoretical models in remote sensing. Since every natural vegetation canopy changes through growth, and its canopy components and architecture are intrinsically variable, reproducibility is seriously limited and measurements of biophysical parameters, such as leaf area index and leaf angle distributions, are prone to large uncertainties. In contrast, the artificial canopy provides a facility for "ground truth" measurements, testing and calibration of instruments, verification, and sensitivity testing of theoretical models as well as specific instruments. A synopsis of this proposal is attached.

If our preliminary findings about the invariance of typical local extremes in surface reflectance patterns to atmospheric perturbations can be further substantiated, then important conclusions should be drawn for the operation of future earth observing satellites. This result leads to the recommendation that off-nadir satellite observations in the near-infrared may contribute additional valuable information to crop identification as well as other scene identification when enough non-Lambertian (e.g. specular) reflectance is present. For crop identification it might be sufficient to swing an MSS or TM type scanner into the downward sun direction to observe the hot spot, and then rotate the instrument around a 360° azimuth for the constant solar zenith angle.

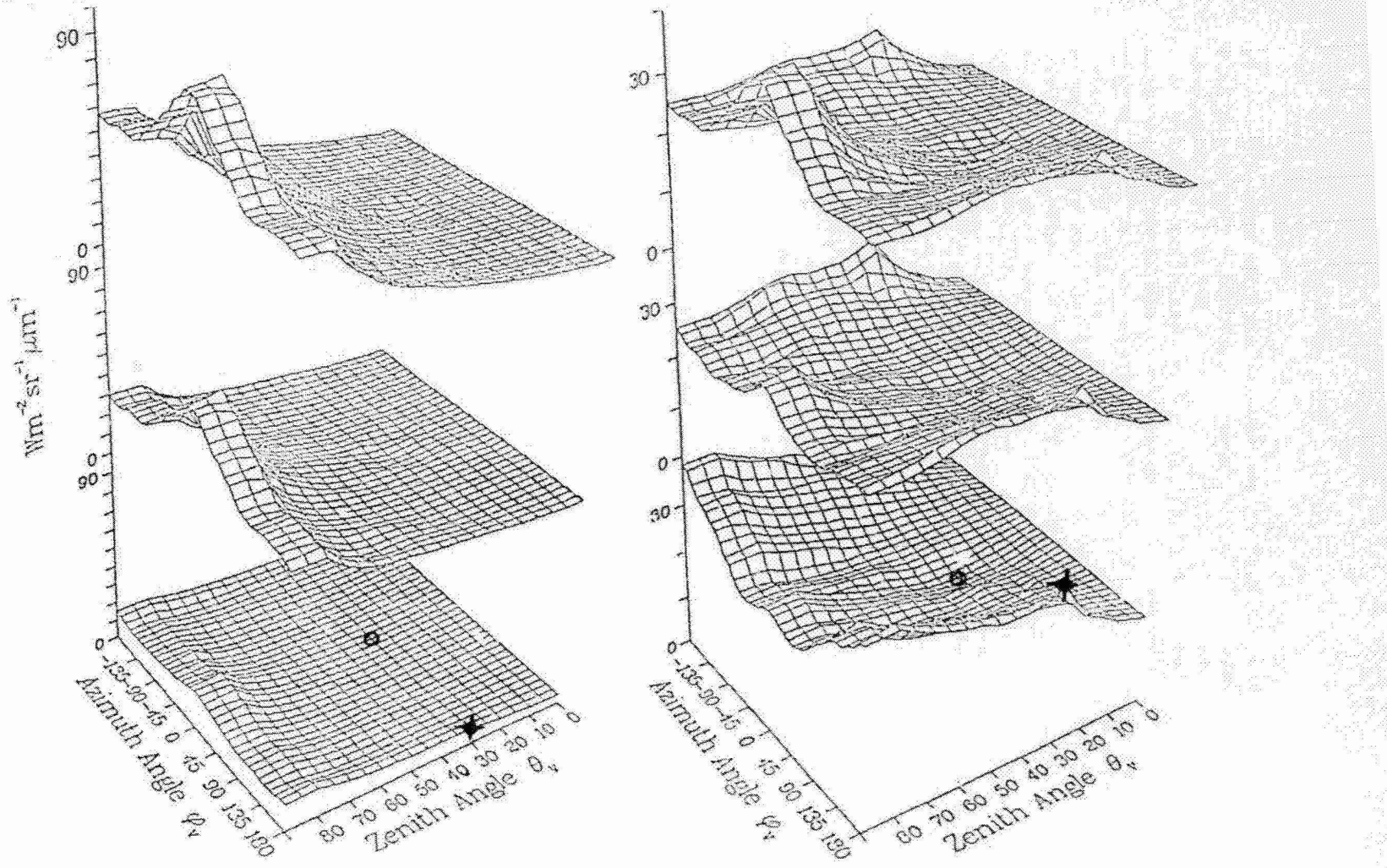
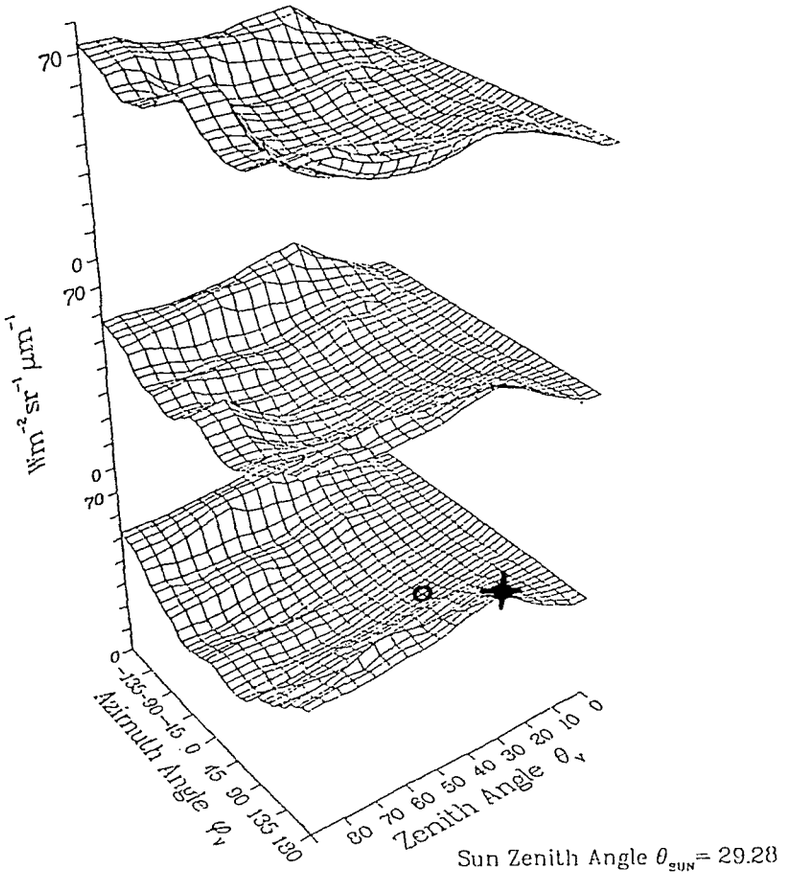


Figure 1. Los Alamos Calculations, November 1984, ConiferousForest: Bottom boundary condition is measured Bidirectional Reflectance Distribution Function (BRDF) of coniferous forest by Kriebel (1977). Atmospheric model: Mid-latitude summer, rural boundary layer aerosol with visual range V_o = 23 km, total optical depth of atmosphere τ = 0.45. Surfaces refer to 0.0, 1.0, and 70 km from bottom to top. Surfaces show the up-welling radiance distribution at 0.65 (left) and 0.85 μm (right) for solar zanith angle 29.3°. Sundirection and direction opposite to sun are indicated by ✦ ("hot spot") and ○, respectively.



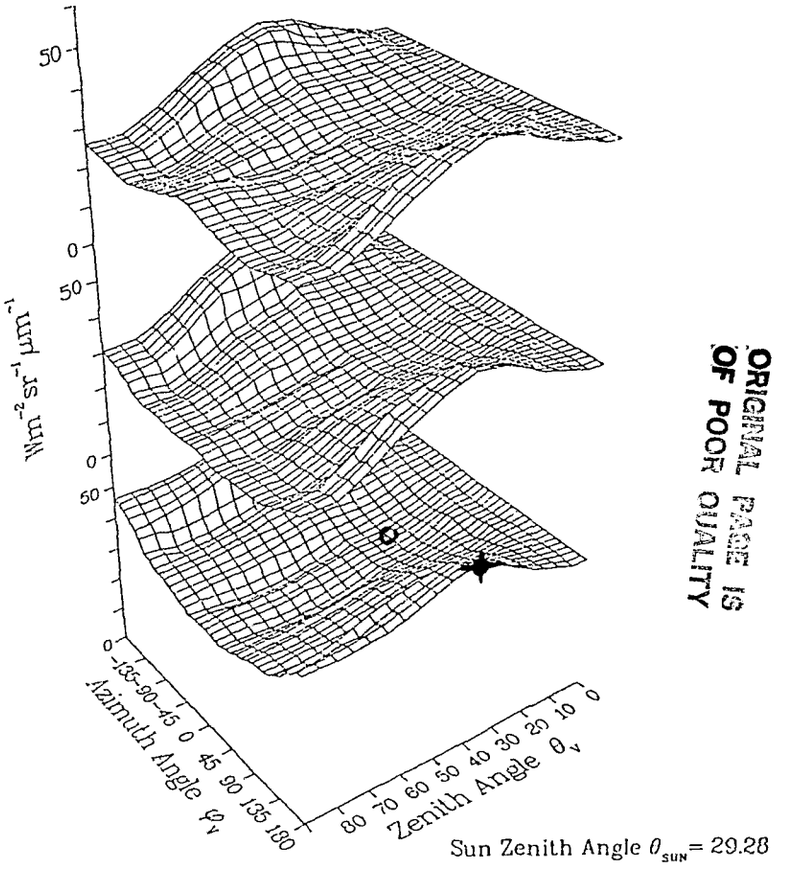


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Figure 2. Los Alamos Calculations, November 1984, Savannah: Bottom boundary condition is measured Bidirectional Reflectance Distribution Function (BRDF) of Savannah by Kriebel (1977). Atmospheric model: Mid-latitude summer, rural boundary layer aerosol with visual range V_O = 50 km, total optical depth of atmosphere τ = 0.25. Surfaces refer to 0.0, 1.0, and 70 km from bottom to top. Surfaces show the up-welling radiance distribution at 0.65 (left) and 0.85 μm (right) for solar zenith angle 29.3°. Sun direction and direction opposite to sun are indicated by ✦ ("hot spot") and O, respectively.

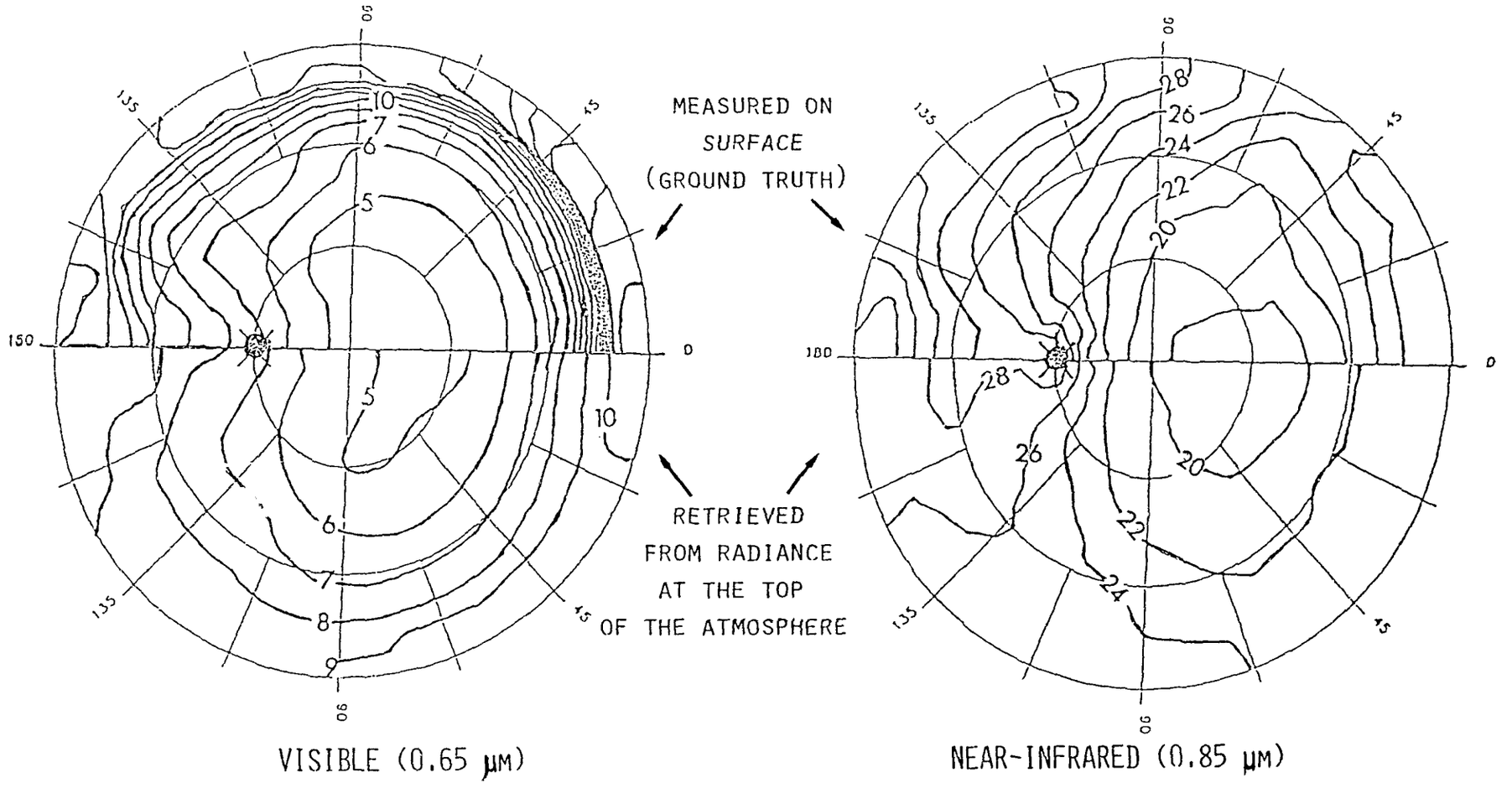

Figure 3. Upwelling radiance distribution of coniferous forest at surface (upper half) compared with radiance at top of the atmosphere, corrected for the atmospheric perturbation (lower half). V_o = 23 km.

N86-13807

SCATTERING MODELS AND BASIC EXPERIMENTS IN THE MICROWAVE REGIME

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1. Introduction

The objectives of the research over the next three years are:
(1) To develop a randomly rough surface scattering model which is applicable over the entire frequency band.
(2) To development computer simulation method and algorithm to simulate scattering from known randomly rough surfaces, $Z(x,y)$.
(3) To design and perform laboratory experiments to study geometric and physical target parameters of an inhomogeneous layer.
(4) To develop scattering models for an inhomogeneous layer which accounts for near field interaction and multiple scattering in both the coherent and the incoherent scattering components.
(5) Comparison between theoretical models and measurements or numerical simulation.

Although various new approaches in rough surface scattering have appeared in the literature, they are generally restricted to either low or high frequency regions because of the simplifying assumptions used. General theories which are not restricted by such simplifying assumptions are so complex that either no explicit solutions are available or only the scattered field is available because the average scattered power is too involved to compute. In order to obtain a general scattering model for randomly rough surface which is explicit and simple to use it is necessary to determine a sufficiently accurate surface current including just enough multiple scattering terms to have the correct behavior over the entire frequency band but not too involved to deny an explicit solution. This is our goal for a rough surface scattering model. In volume scattering problems most theories are restricted to either a sparsely populated medium or coherent scattering in a dense medium. Incoherent scattering which is of major interest in remote sensing has been investigated mainly by either the Born or the distorted Born approximation in the field approach and the radiative transfer formulation in the intensity approach. Other methods are needed to include multiple incoherent scattering in the field approach and techniques are needed to determine the autocorrelation function in the coherent field calculation in dense inhomogeneous medium. Currently, the use of Percus Yevick approximation and the associated pair distribution function for hard spheres in coherent scattering computation leads to nonphysical results when the volume fraction of the medium is around 0.6.

All theoretical scattering models involve some simplifying assumptions. To verify these models it is best to have controlled experiments so that target parameters can be varied and

any given experiment can be repeated. In the case of random surfaces it is possible to use computer simulation. This is not only cost effective compared with full scale field measurements but it is also more convenient to change target parameters than in any controlled experiment.

2. Approach

The approach to be used to develop the proposed random surface model is to use the integral equation method. We have used this method successfully to develop a scattering model for a perfectly conducting surface in the past year and we intend to generalize it to dielectric surfaces. To perform computer simulation for the rough surface problem we intend to investigate first the generation of a two- dimensional random surface with specified autocorrelation function. This is a major effort because algorithms and techniques for this purpose have been restricted to one-dimensional surfaces. From the numerical point of view this is also a large job requiring large capacity computer. Past experience on a one-dimensional surface indicates that it is desirable to have at least a 10,000 point surface to insure convergence of statistical parameters and it is desirable to have a 50,000 point surface to allow scattering computation at different frequencies. Once the surface is available the standard moment method will be used for scattering coefficient computations. Here again it is necessary to generalize from one to two dimensions and numerically this is a problem because we cannot allow the computation-size to increase like a square.

The measurement program will be divided into two major tasks, (1) the design and construction of a versatile volumetric target structure, and (2) the measurement of radar backscatter cross section as a function of system and target parameters. The target is designed and constructed to simulate vegetation type structures. The target can be used to provide a variety of both geometric and electrical characteristics to include, leaf density in three dimensions, leaf orientation and location, leaf size and shape,and permittivity characteristics of the volumetric structure including relative permittivity and conductivity. The target is designed to allow a number of different parameters to be evaluated while maintaining the basic target shape. Measurements will include the effects of leaf distribution, shape, orientation and location on radar backscatter. Initial experiments will minimize the effects of the stalk structures, however, future measurement programs could include these interaction effects as well. The measurements will be made in an indoor Radar Cross Section Range. The measurements will include amplitude and phase measurements at X band,K band, incident angles from 0 to 50 degrees, and the four linear transmit/receive polarization states.

In view of the difficulties with the current theoretical approaches as stated in the introduction to the volume scattering problem, we propose to use the eikonal approximation for incoherent

scattering computation and the solution of the master equation for determining a more realistic autocorrelation function. It should be noted that the pair distribution function was derived for use in a dynamic medium such as a fluid. Hence, for a medium with random but rigid distributions of particles it is not appropriate and does lead to nonphysical results.

3. Results to Date

Over the past year we have developed a scattering model for an inhomogeneous layer containing needle- shaped leaves. We have made comparisons between scattering from such a layer and another layer containing disc-shaped leaves. The significant difference between the two types of vegetation is that the backscattering angular curve for the disc-type has a hump in the mid angular region while the needle-type has a dip in the same region when the size of the leaves is comparable to the incident wavelength(see Figures 1 and 2). In addiction, study has also been carried out to determine the effects of Fresnel phase in the scattering phase matrices on scatterers that are comparable to the incident wavelength but are much smaller than the wavelength in at least one dimension. The conclusion is that the inclusion of the Fresnel phase gives a more accurate frequency trend dependence (see Lee;1984). Also studied is the effect of closer spacings between scatterers accounted for in the scattering phase matrix. Results indicate that a more accurate target parameter can be inferred from such a model than is possible using a standard radiative transfer method (Fung and Eom;June,1984). The inversion from measurements for albedo and optical depth was studied by Fung and Eom (August,1984) with the conclusion that at least a first-order theory must be used in the radiative transfer formulation for emission from an inhomogeneous layer.

A scattering model for a perfectly conducting, randomly rough surface has been developed which is valid over the entire frequency band (Pan;1984). It has been demonstrated analytically that the general solution obtained reduces correctly to the geometrical optics solution in the high frequency limit and to the first-order small perturbation solution in the low frequency limit. In the intermediate region it has a behavior which can be very different from either limiting solution but is liable to be misinterpreted as one or the other. The reason is that it could resemble the low frequency solution in polarization behavior but follow the general angular trend of the Kirchhoff solution(see Figure 3). Also developed was the scattering model for a perturbed sinusoidal surface (Eom and Fung,1984). This was done to account for soil surfaces with row directional dependence.

A plastic model for a layer of leaves of either circular or elliptic shape has been designed which permits the leaf angular distribution, leaf size, leaf density, leaf dielectric value, and row direction effects to be studied under laboratory conditions. It is expected that measurements conducted with this target will be able to provide reliable data for the verification of existing volume scattering models.

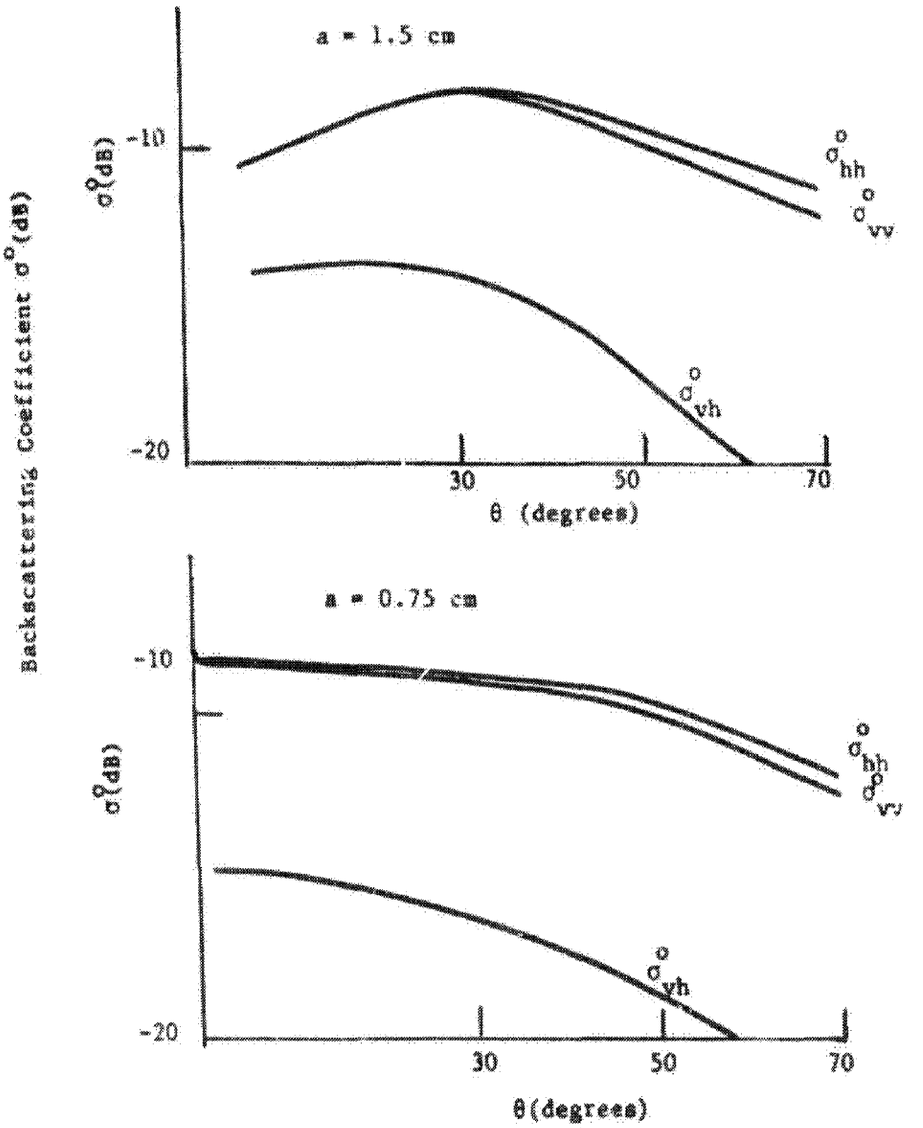

FIG 1. SIZE DEPENDENCE OF DISC-SHAPED VEGETATION (a= radius of disc)

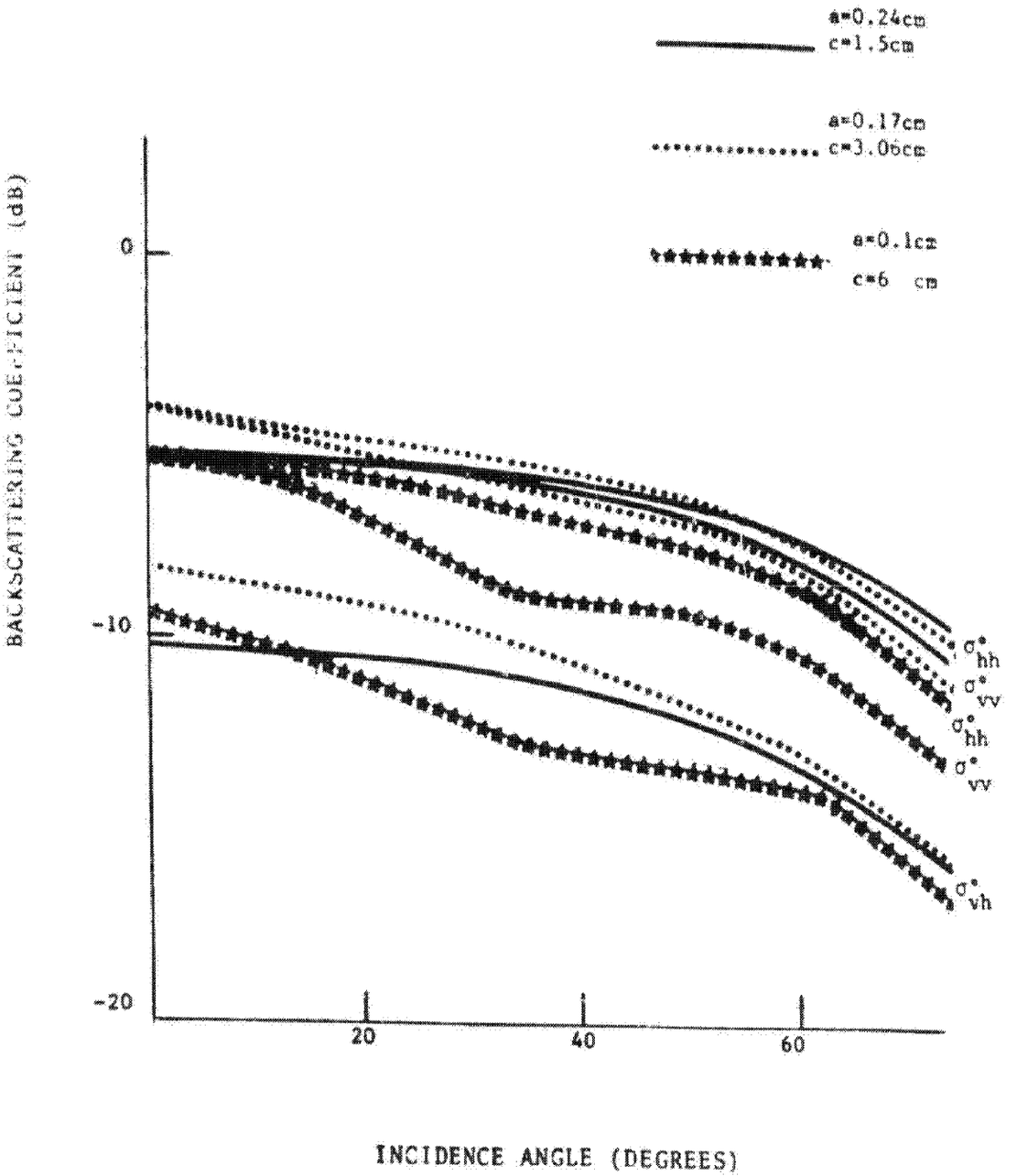

FIG 2. SIZE DEPENDENCE OF NEEDLE-SHAPED VEGETATION (a= radius; c= length of needle)

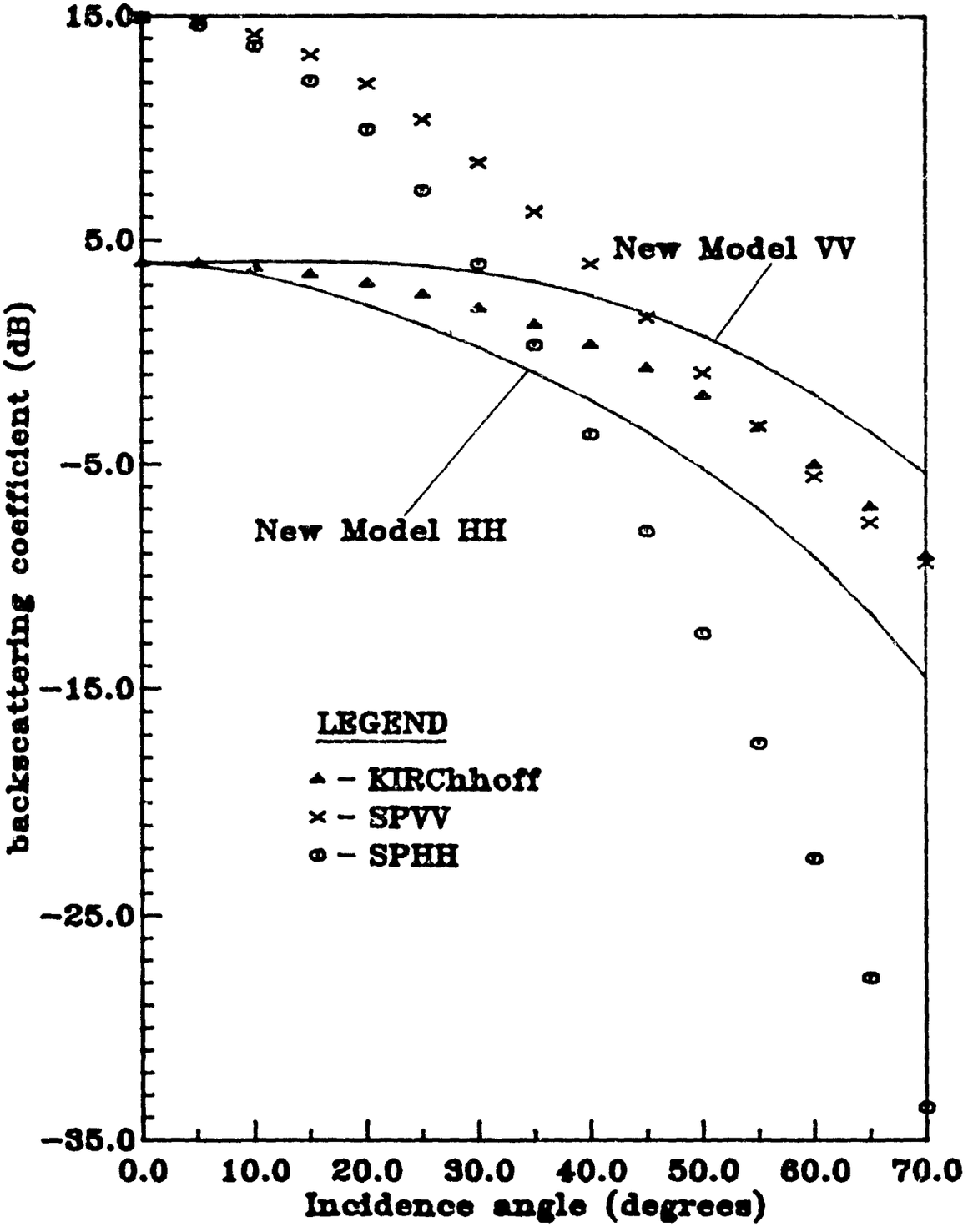

FIG 3 Comparison of INEQ with FOSP and KM (kσ=1.0 and kℓ=2.79).

N86-13808

REMOTE SENSING OF EARTH TERRAIN

Jin Au Kong

Massachusetts Institute of Technology

1. Objective

The objective of this research is to develop theoretical models that are useful and practical in the remote sensing of the earth environment including the earth terrain, the lower and the upper atmospheres. We have been very successful in developing various models applicable to the microwave remote sensing of vegetation, snow-ice, and atmospheric precipitation. We shall extend such studies to the higher frequency range to unify the optical band and the microwave theoretical foundations. We shall also extend our study, which had an emphasis on vegetation canopy to include all terrain media, and the whole earth environment. A data base will be developed to generate scene radiation characteristics which will benefit the studies of global inhabitability, meteorological applications, and crop yield.

2. Technical Approach

The radiative transfer theory has been fully developed to treat the volume and rough surface scattering effects. The combined random rough surface and volume scattering effects have been studied by employing a Gaussian random surface and applying the small perturbation methods which are modified with the use of cumulant techniques. The rough surface effects are incorporated into the radiative transfer equations by modifying the boundary conditions for the intensities. The T-matrix method, which utilizes vector spherical wave functions for the expansion of incident, scattered, and surface fields is used to derive the extinction matrix and the phase matrix for the radiative transfer equations. Densely distributed spherical dielectric scatterers is studied with the quantum mechanical potential approach. The quasi-crystalline approximation is applied to truncate the hierarchy of multiple scattering equations and the Percus-Yevick result is used to represent the pair distribution function. The modified radiative transfer theory is studied with the Feynman diagrammatic representation. Atmospheric precipitation is also studied with the vector radiative transfer equations by making use of the Mie scattering phase functions and incorporating the rain-drop size distributions. To study scattering by anisotropic medium modelling sea ice and vegetation field with row structures, the dyadic Green's function is first derived and used in conjunction with the first-order Born approximation to calculate the backscattering coefficients.

3. Research Results

In active microwave remote sensing, a two-layer anisotropic random medium model has been developed to investigate the anisotropic effect of sea ice in which, due to the flow of sea water, the brine inclusions are tilted and to study the azimuthally anisotropic behavior of vegetation canopy which is attributed to the orientations of the vegetation stalks. In this scheme, the dyadic Green's function for a two-layer anisotropic medium is developed and used in conjunction with the first order Born approximation to calculate the backscattering coefficients. It is shown that strong cross-polarization occurs in the single scattering process and is indispensable in the interpretation of radar measurements of sea ice at different frequencies, polarizations, and viewing angles. The effects of anisotropy on angle responses of backscattering coefficients are also illustrated. For passive microwave remote sensing of a two-layer anisotropic random medium, the principle of reciprocity is invoked to compute the brightness temperatures. The bistatic scattering coefficients are first calculated with Born approximation and then integrated over the upper hemisphere to be subtracted from unity, in order to obtain the emissivity for the random medium layer. The theoretical results are illustrated by plotting the emissivities as functions of viewing angles and polarizations. They are used to interpret remote sensing data obtained from vegetation canopy where the aniostropic random medium model applies. Field measurements with corn stalks arranged in various configurations with preferred azimuthal directions are successfully interpreted with this model.

The problem of microwave scattering from periodic surfaces is solved by using a rigorous modal technique which conserves energy, obeys reciprocity, and takes into account the multiple scattering and shadowing effects. The theoretical results have been applied to the calculation of the radar backscattering cross sections in active remote sensing and the brightness temperatures in passive remote sensing, and used to match field data from soil moisture measurements. The angular behavior of the brightness temperatures has been explained with the threshold phenomenon by considering the appearance and disappearance of the various Floquet modes. The Kirchhoff approximation is used to study the scattering of electromagnetic waves from randomly perturbed quasi-periodic plowed fields. The narrow-band Gaussian random variation around the spatial frequency of the sinusoidal variation is used to introduce the quasiperiodicity. The physical optics integral is evaluated to obtain closed form solutions for coherent and incoherent bistatic scattering coefficients. In the geometrical optics limit, it is shown that the bistatic scattering coefficients are proportional to the probability of the occurrence of the slopes which will specularly reflect the incident wave into the observation direction. The theoretical results are illustrated for the various cases by plotting backscattering cross sections as a function of the incident angle. It is shown that there is a large difference between the cases where the incident wave vector is parallel or perpendicular to the row direction. When the incident wave vector is perpendicular to the row direction, the maximum value of the backscattering cross section does not necessarily occur at normal incidence. The scattering coefficients can be interpreted as a convolution of the scattering patterns for the sinusoidal and for the random rough surfaces. For the backscattering cross sections we observe the occurrence of peaks the relative magnitudes and locations of which are explained in terms

of the scattering patterns for sinusoidal surfaces. The combined random rough surface and volume scattering effects have been studied by employing a Gaussian random surface and applying the small perturbation methods which are modified with the use of cumulant techniques. The rough surface effects are incorporated into the radiative transfer equations by modifying the boundary conditions for the intensities. The radiative transfer equations are then solved numerically using the Gaussian quadrature method and the results are illustrated and compared with experimental data.

The radiative transfer theory is applied to calculate the scattering by a layer of randomly positioned and oriented nonspherical particles. The scattering amplitude functions of each individual particle are calculated with Waterman's T-matrix method, which utilizes vector spherical wave functions for the expansion of incident, scattered, and surface fields. The orientation of the particles is described by a probability density function of the Eulerian angles of rotation and a rotation matrix is used to relate the T-matrix of the principal frame to that of the natural frame of the particle. The extinction and phase matrices for the radiative transfer equations are expressed in terms of the T-matrix elements. The extinction matrix for nonspherical particles is generally nondiagonal. It is shown that there are only two attenuation rates in a specified direction of propagation. The scattering of a plane wave obliquely incident on a half space of densely distributed spherical dielectric scatterers is studied with the quantum mechanical potential approach. The quasi-crystalline approximation is applied to truncate the hierarchy of multiple scattering equations and Percus-Yevick result is used to represent the pair distribution function. While results at high frequencies are calculated numerically, closed form solutions are obtained in the low frequency limit for the effective propagation constants, the coherent reflected wave and the bistatic scattering coefficients.

In the strong fluctuation theory for a bounded layer of random discrete scatterers, the second moments of the fields in the second order distorted Born approximation are obtained for co-polarized fields. The backscattering cross sections per unit area are calculated by including the mutual coherence of the fields due to the coincident ray paths, and those due to the opposite ray paths, corresponding to the ladder and cross terms in the Feynman diagrammatic representation. It is proved that the contributions from ladder and cross terms for the co-polarized backscattering cross sections are the same, while the contributions for the cross-polarized backscattering cross sections are of the same order. The bistatic scattering coefficients in the second order approximation for both the ladder and cross terms are also obtained. The contributions from the cross terms explain the enhancement in the backscattering direction.

Both passive and active remote sensing of atmospheric precipitation are studied with the vector radiative transfer equations by making use of the Mie scattering phase functions and incorporating the rain drop size distributions. For passive remote sensing we employ the Gaussian quadrature method to solve for the brightness temperatures, and for active remote sensing an iterative approach carryied out to second order in albedo is used to calculate the bistatic scattering coefficients and the backscattering cross sections per unit volume.

4. Significance of Results

The anisotropic medium model that has been developed is now able to account for the like as well as cross polarization measurements of the backscattering cross sections in active remote sensing of sea ice. The same model applies to the interpretation of data from the passive remote sensing of vegetation field. Extending this two-layer medium model to multilayered configuration will facilitate the interpretation for more complicated scene radiation characteristics.

The strong fluctuation theory has been successfully developed to account for the volume scattering effects, not only for earth terrain media such as vegetation and snow-ice fields, but also for the remote sensing of atmospheric precipitation. The periodic rough surface theory provides a rigorous approach that satisfies both the principle of reciprocity and the principle of energy conservation.

5. Next Major Steps

There are three major steps: 1) To extend our study to include the effects of the upper atmosphere such as the troposphere, the ionosphere, and the magnetosphere. Our initial success with the usage of the random medium model applied to atmospheric precipitation serves as a solid starting point. 2) To extend our study to other earth terrain medium configurations such as canopy-covered soil moisture investigation, snow-covered fields, and layered-medium model including both volume scattering and rough surface scattering effects. 3) To extend our study to unify the theoretical foundation for the microwave and the optical spectra. The starting point is the application of the radiative transfer theory, which has been developed in both frequency ranges rather independently.

N86-13809

DISCRETE RANDOM MEDIA TECHNIQUES FOR MICROWAVE MODELING OF VEGETATED TERRAIN

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1. Introduction

Microwave remote sensing of vegetated terrain has been studied. Vegetation is modeled so that backscattered radar signals can be used to infer parameters which characterize the vegetation and underlying ground. The vegetation is modeled by discrete lossy dielectric scatterers with prescribed characteristics. The goal of the modeling effort is to remotely sense vegetation type (classification), growth stage, and plant/ground moisture. This information can then be used as input into agricultural, forestry and global circulation models. The microwave frequency spectrum, particularly L and C bands, are especially appropriate for this purpose since the wavelength is comparable to plant leaf and stem size. The resulting resonant interaction leads to backscattered data highly depend on plant shape and orientation. In addition, the transparent nature of the atmosphere in this frequency regime allows for algorithm development which requires no atmospheric correction.

2. Technical Approach

The modeling approach characterizes the vegetated terrain as a layer of plant growth over a possibly rough surface. The plants are viewed as composites of leaves and stems which are modeled by dielectric discs (not necessarily circular) and rods. The discs and rods are placed at random locations throughout the layer; their size and orientation statistics are chosen to correspond to the vegetation being modeled.

Once the discrete stochastic model has been specified, the average backscattering coefficients are computed for both like and cross polarizations. The calculation is made amenable to analysis by the presence of a small parameter - the fractional volume of vegetation. It is then possible to employ the distorted Born approximation or transport theory (depending on albedo size) to calculate the backscattering coefficients. This constitutes the formulation of the discrete problem, i.e., given the distribution of scatterer sizes and orientations, the backscattered power can be computed. The final step in the procedure to obtain a remote sensing algorithm is to invert this direct problem. The performance of the inversion assumes that the backscattering coefficient is given as a function of angle of incidence and/or frequency. From this data, the statistical characteristics of the scatterers are computed. This calculation is often numerically ill-conditioned and needs special treatment.

3. Research Results

Over the three year period, results have been obtained in all areas needed for algorithm development. Electromagnetic modeling of plant elements has been addressed, backscattering coefficients have been calculated and inversion algorithms have been developed.

Simple plant canopies such as soybeans can be modeled by replacing the plant's leaves and stems by dielectric discs and rods respectively as is shown in Fig. 1. The relative dielectric constant used for the discs and rods is the equivalent dielectric constant of the plant material. The use of this equivalent dielectric neglects scattering effects caused by internal variations within the plant. This is small however, because of the long wavelength involved.

Scattering amplitudes have been computed for both the disc and stem elements. The resulting formulas for the scattering amplitudes are particularly simple because they take advantage of the small ratio of thickness to radius in the case of the discs and radius to length in the case of the rods. The simple formulation is particularly important since the results must be averaged over both inclination and size distributions.

Backscattering from the modeled plant canopy has been treated by two techniques: the distorted Born approximation and the transport theory. The two methods are equivalent when the albedo of the scatterers is small and no coherent (planar) boundaries are present. It has been shown for the case of a flat ground that the transport theory neglects certain coherent interference terms which are taken into account by the distorted Born approximation. It should be noted that this effect is a low frequency (L-band) phenomenon because at higher frequencies the surface appears rougher, and as a result, coherence effects disappear. Since the distorted Born method is applicable in the L band frequency regime, since it contains the interference terms and since it is relatively simple in formulation as compared to vector transport theory, it has been used almost exclusively, to calculate the backscattering coefficients.

Application of the distorted Born theory to the modeling of crops such as soybeans has yielded interesting results. Fig. 2 shows some of these results for a frequency of 1.5 GHz. The figure is a plot of σ^0_{VV} versus angle of incidence. An examination of the figure shows that for vertical-like polarized returns the leaves are dominant at low angles and the stems are most important at large angles of incidence. This is not surprizing since the electric field is aligned with most stems at large angles of incidence.

The model whose results are shown in Fig. 2 consists of leaves having radii of 2.5, 3.5 and 5.0 cm. Each of these leaf types has a density of 333/m . The stems are all taken to be 20 cm long and with a density of 1000/m . The leaf and stem size characteristics were obtained by the principal investigator who made on-site measurements at Beltsville.

Although Fig. 2 just shows the vertical-vertical backscattering coefficient, simple expressions were obtained for the horizontal-horizontal case as well as the cross polarized returns. These appear to be valid for frequencies below 4 GHz as long as the correct dielectric constants for the discs and rods are used. The de-Loor formula has been used for the calculation of disc and stem dielectric constants however, at lower frequency ($\simeq$ 1-2 GHz) a conductive contribution should be included.

The final step in any remote sensing problem is the inversion process. Results in this area have been obtained this year. Attention has been focused on the relationship between the backscattering coefficient σ^0_{hh} and the joint probability density of disc radii and inclination angles. The expression derived by the distorted Born approximation has been used. An examination shows that it is nonlinear in nature. The relationship has been linearized in the 1-2 GHz region where the skin depth is large. The linearized expression (a Born approximation) is a Fredholm integral equation of the first kind. Inversion problems of this type are usually ill-conditioned and must be regularized.

To simplify the inversion procedure further, it has been assumed that the radii and inclination angle densities are independent. If it is assumed that the density of one variable is known, then the other can be found through the integral equation with the knowledge of the backscattering coefficient for various angles of incidence. Such an inversion is shown in Fig.3. Here the leaves have fixed radius of 4 cm. The inclination angles density is shown by the solid line in Fig. 3. The combined joint density is then used to generate σ^0_{hh} for various angles of incidence. The calculated values of the backscattering coefficient are corrupted by noise and a Phillips-Twomey inversion algorithm is used to compute the inclination angle density at certain discrete points. The results, which are good, are shown by small circles, squares and stars in Fig. 3.

The Phillips-Twomey method has also been applied to the inversion of the complete two-dimensional density of radii and inclination angles. Here it has been assumed tht backscattering data is known at different angles of incidence and for different frequencies.

4. Significance of Results

The results just presented provide a direct relationship between the backscattering coefficient and the detailed parameters that characterize the scatterers. This means that by remote L band radar measurements at different angles of incidence and for different frequencies, such quantities as leaf inclination angle distribution and leaf area distribution can be determined. These distributions can then be directly used to estimate growth stage by knowledge of the area density of leaves and to estimate stress, due to lack of water, by knowledge of the inclination angle density.

5. Future Work

The model developed thus far has been directed toward leafy agricultural crops such as soybeans. By incorporating other scattering types of a more complex nature, other crops and forests can be modeled and inversion algorithms developed. Future scatterer development should include the modeling of non-planar leaves, branches and stalks with periodic nodes (corn).

An experiment should be planned so that the theoretical developments can be tested. The experimental approach is particularly important in the inversion algorithm development since equipment limitations can force consideration of different inversion techniques

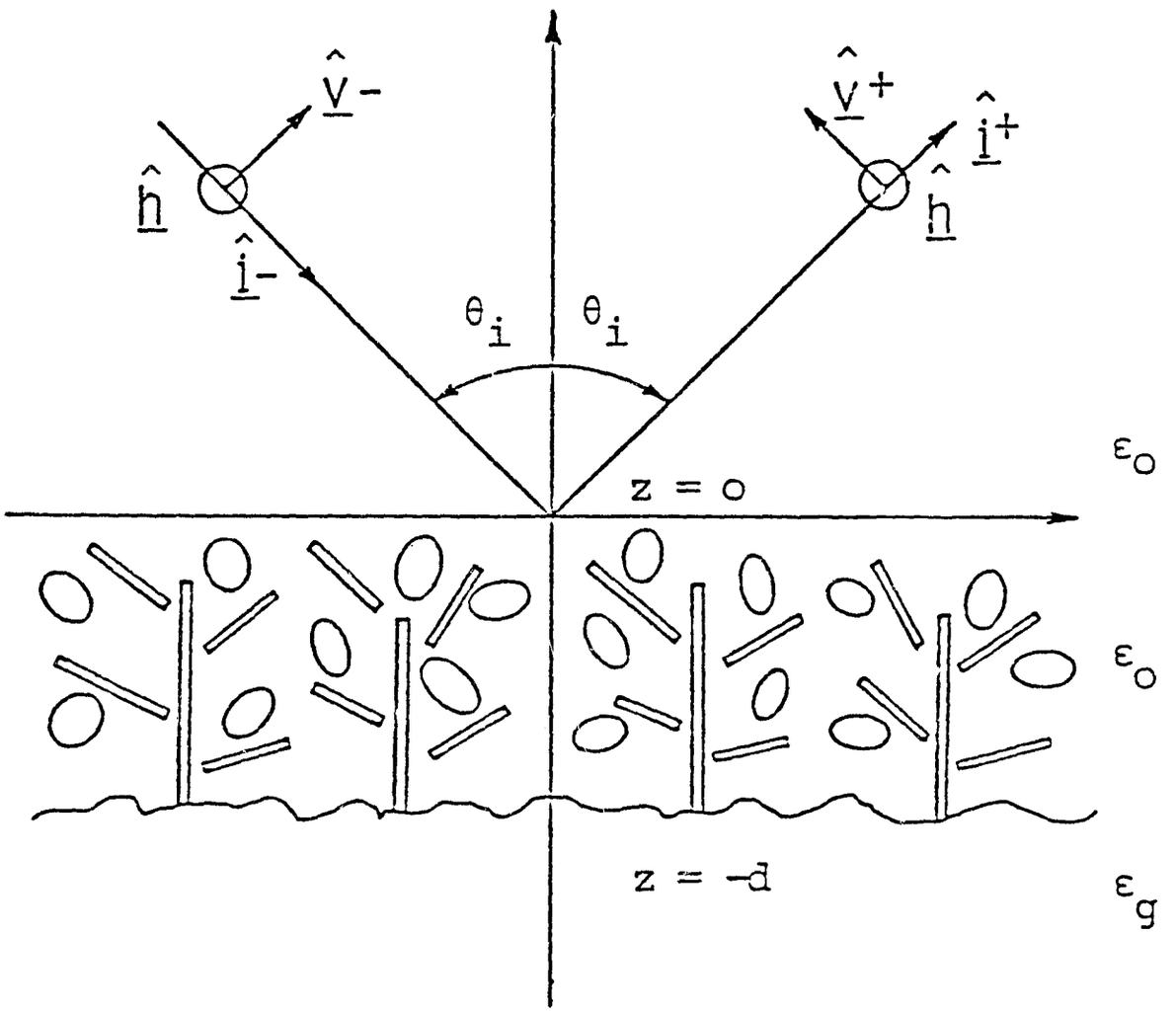

Fig. 1. Vegetation Layer Modeled by Leaves and Stems

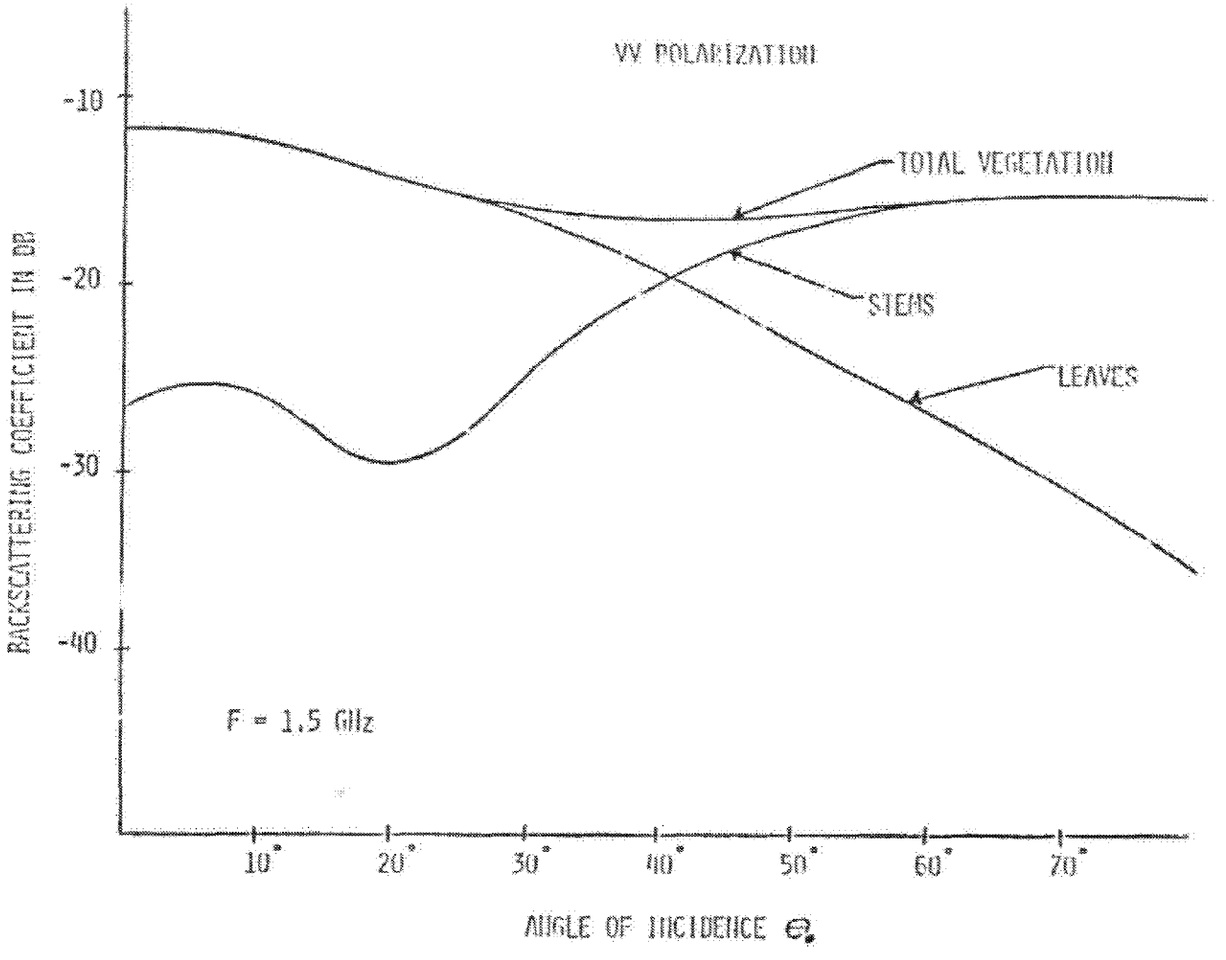

Fig. 2. Backscattering Coefficient versus Angle of Incidence for Mature Soybean Model

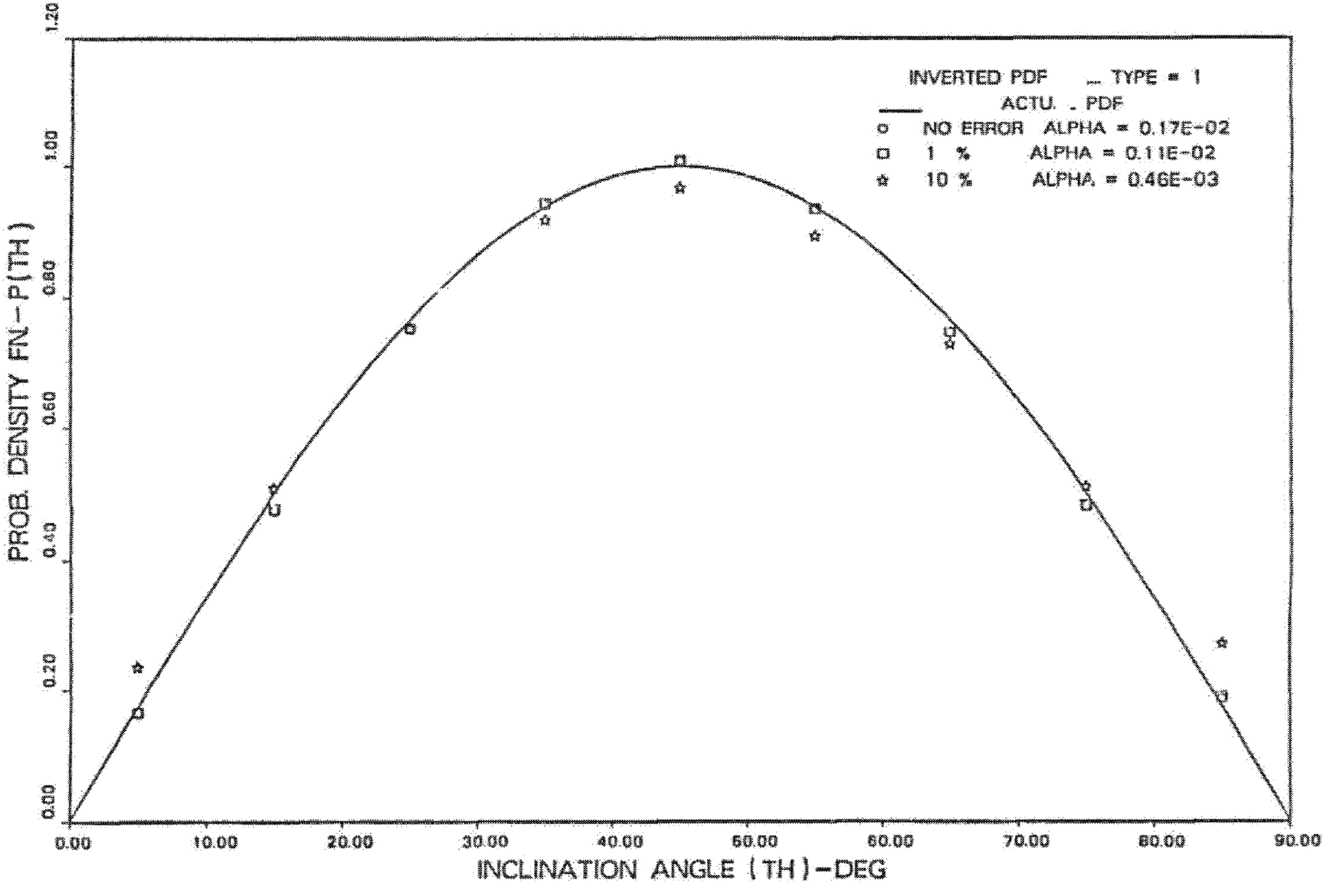

Fig. 3. Probability Density Inversion versus Leaf Inclination Angle.

N86-13810

MICROWAVE DIELECTRIC AND PROPAGATION PROPERTIES OF VEGETATION CANOPIES

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A vegetation canopy is a highly inhomogeneous medium at microwave frequencies, and because the scattering elements (leaves, stalks, fruits, and branches) have a nonuniform distribution in orientation, the canopy is likely to exhibit nonisotropic attenuation properties. In some canopies, the stalk may contain the overwhelming majority of the plant's biomass, which suggests that an incident polar wave would be differentially attenuated by the canopy depending on the direction of the incident electric field relative to the stalks' orientation. The propagation properties of a vegetation canopy play a central role in modeling both the backscattering behavior observed by an imaging radar and the emission observed by a radiometer. These propagation properties are in turn governed by the dielectric properties and the size, shape, and slopedistributions of the scatterers. In spite of the critical need for canopy propagation models and experimental data, very few investigations had been conducted (prior to this study) to determine the extinction properties of vegetation canopies, either by constituent type (leaves, stalks, etc.) or as a whole.

A three-faceted approach was undertaken in this study consisting of complimentary investigations with each providing answers to specific aspects of the overall question. The first facet consisted of dielectric measurements that were conducted over the 1-10 GHz band to determine the variations of the dielectric permittivity and loss factor as a function of water content and salinity. Dielectric mixing models were developed and evaluated against the experimental data for individual plant parts (leaves, stalks, fruit) of several types of plants (wheat, corn, and soybeans). An example is shown in Fig. 1.

The second facet of the study consisted of direct measurements of canopy attenuation. Using truck-mounted radars as transmitting sources positioned above the canopy, and small receive antennas mounted on fiberglass rails underneath the canopy (on the soil surface), attenuation measurements were conducted as a function of incidence angle (relative to nadir), microwave frequency, and polarization configuration. In addition, special experiments were conducted to evaluate the relative contributions of the various canopy constituents to the total loss (or attenuation) factor of the canopy. These included wheat decapitation experiments, in which measurements of the canopy loss factor were made before and after cutting off and removing the wheat heads, and soybean defoliation experiments

which provided comparison of the extinction loss due to the stalks alone with the total loss due to the stalks and leaves together. According to Fig. 2, the stalks account for the majority of the propagation loss in a soybeans canopy for vertically polarized waves, whereas the leaves are the dominant absorbers for horizontal polarization.

A canopy propagation model was developed consisting of three terms: (a) leaf term that accounts for absorption by randomly oriented disc-shaped leaves, (b) a stalk term that accounts for absorption by a uniaxial crystal consisting of thin, vertical, lossy cylinders in an air background, and (c) a branch term that accounts for the loss by a medium containing randomly oriented needle-shaped branches. The first and third terms are polarization-independent and vary with incidence angle as sec θ. The stalk term has a strong dependence on both polarization and incidence angle. The model was found to be in good agreement with experimental observations. One of the key parameters in the model is the dielectric constant of the vegetation material, which was calculated using the dielectric mixing models developed in the first facet of this investigation. The combination of the dielectric mixing model and the canopy propagation model provides the means to compute the loss factor of the canopy if given the water contents and volume fractions of the canopy constituents and the canopy height. The model accounts for the dependence on incidence angle, polarization and wavelength.

In the next facet of this study, we attempted to relate the results obtained above to the remote sensing problem. In order to focus the study on the canopy itself and avoid problems associated with variations in the soil background, it was decided to cover the soil surface with screen wire and make passive microwave observations as a function of time over the growing cycle. The screen wire, while it has no discernible effect on the growth of the plants, acts as a conducting surface with a near-zero emissivity. Thus, soil moisture variations exercise no influence on the canopy emission. This technique was used to investigate the variation of the brightness temperature of the canopy with look direction (relative to the row direction), incidence angle, and polarization configuration for wheat, soybeans, and corn canopies. A radiative transfer model was used to relate the brightness temperature to biophysical parameters of the canopy through the canopy loss factor. Figure 3 shows that the experimental observations are in good agreement with the model predictions. A second set of radiometer observations were made for canopies under natural conditions (no screen used). The radiative transfer model was extended to include a soil-moisture term that accounts for the emission and reflection by the soil surface. Again good agreement was found between theory and experiment.

The majority of microwave scattering and emission models reported in the literature have treated the canopy as an isotropic medium. This implies that the attenuation coefficient is independent of polarization, incidence angle, and look direction (in azimuth). The present study has shown that in most

cases, none of the above assumptions are valid. Consequently, modelers will have to incorporate the anisotropic character of the canopy in their models, which is likely to lead to more applicable models for the backscattering and emission from vegetation than now exists.

The work conducted to data has established the overall functional relations between the propagation coefficients of a vegetation canopy and its biophysical and geometrical properties. The results, however, are based on a number of specific experiments that were conducted for a specific set of crops at specific stages of growth. The goal of the next phase of this study is to develop a general propagation model that may be applied to a wide range of canopy types and conditions. The experimental component of the study will be designed accordingly.

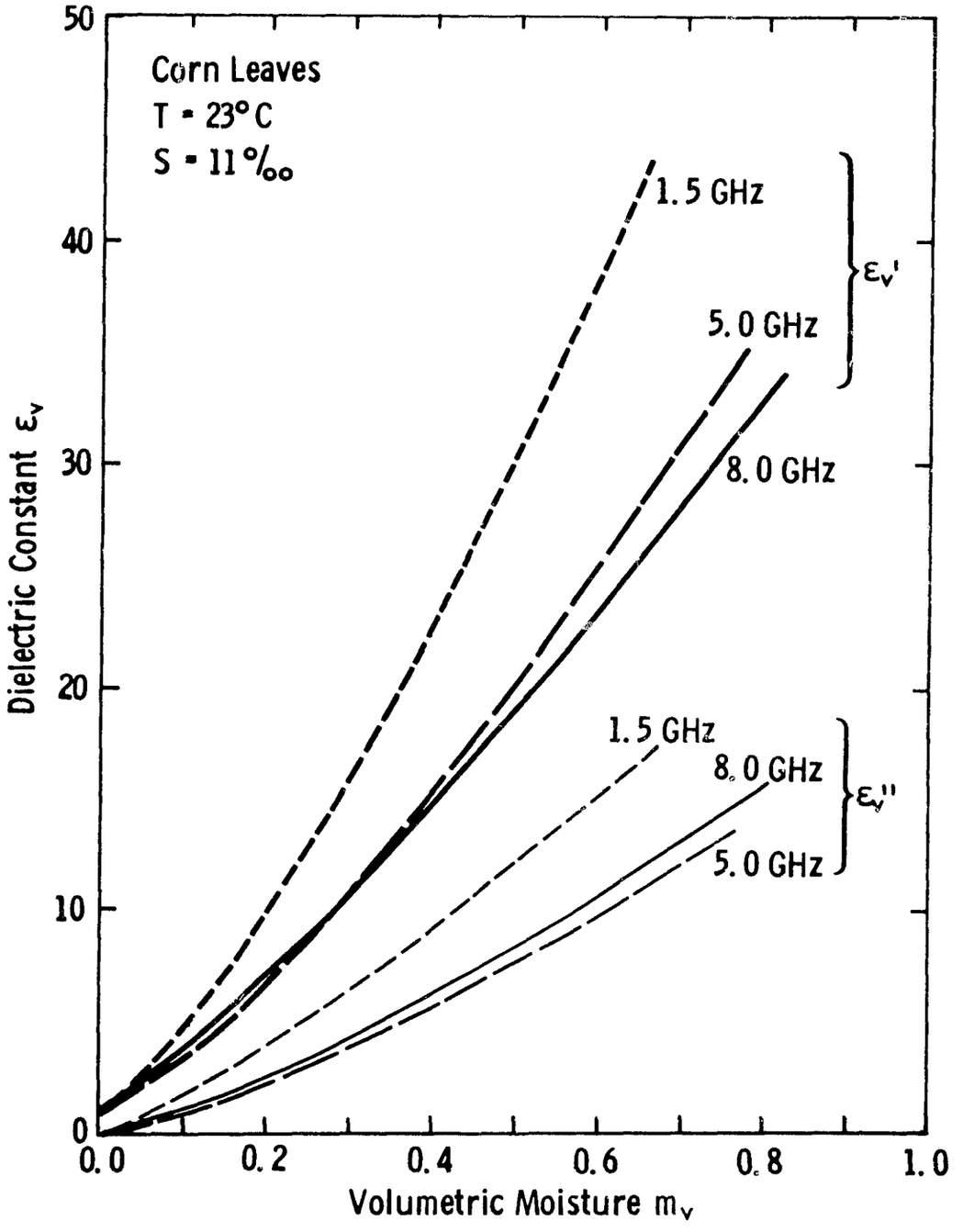

Figure 1. Measured Dielectric Behavior of corn leaves.

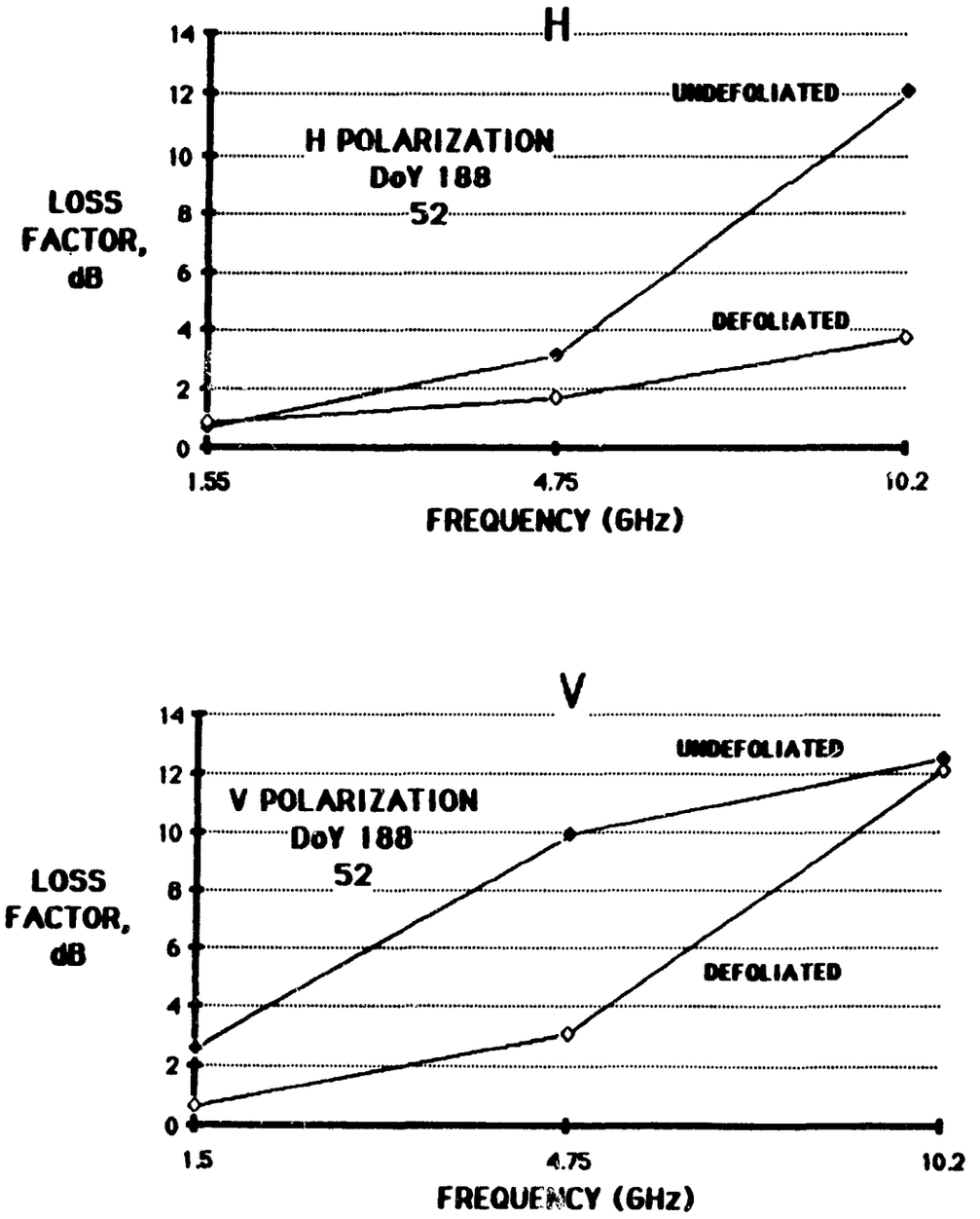

Figure 2. Comparison of attenuation measurements made for soybeans canopy before and after defoliation for vertical and horizontal polarizations.

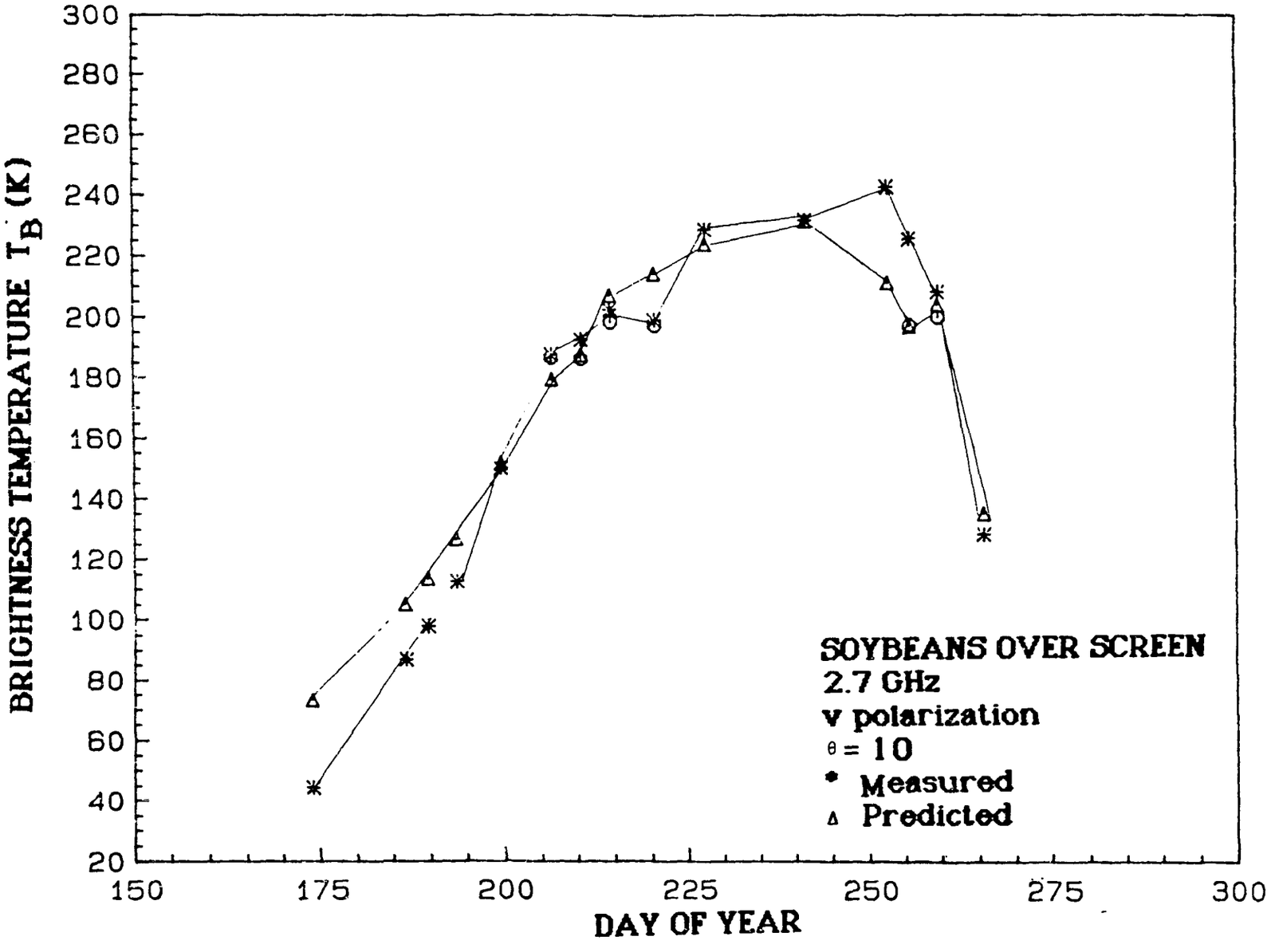

Figure 3. Comparison of the temporal record of the brightness temperature of soybeans canopy with model prediction.

N86-13811

DETERMINATION OF BACKSCATTERING SOURCES IN VARIOUS TARGETS

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OBJECTIVES

The objectives of this research are to identify the primary contributors to 10-GHz radar backscatter from various natural and man-made surfaces and objects, and to use this information in developing new and better models for the scatter. When the true sources are known for the scattering that leads to variation in intensity on radar images, the images (and sets of them) may be interpreted more meaningfully in terms of the variation of parameters of interest for science or application. For example, better interpretation of vegetation images may be possible for yield forecasting and stress detection.

APPROACH

Backscattering coefficient (σ^o) measurements from crops, soil, snow, etc. have been conducted for over three decades, but only a minimal effort has been focused on determining the sources of backscattering in those targets. Using a pulse radar, Graf and Rode [1982] in Germany used a solitary fir tree to determine its major sources of backscattering. Ulaby et al. [1982], using a defoliation technique, conducted scattering measurements on several types of crops. The only previously reported extensive direct measurements of sources of scatter have been conducted by the Remote Sensing Laboratory at the University of Kansas through this research in 1983 [Zoughi et al., 1985; Wu et al., 1985]. The approach and the results of these experiments provided the primary guidelines for the 1984 experiments.

To measure the relative backscattered energy from various constituents in a target (i.e., corn cob, stalk, leaves), a radar system with a fine range resolution and a small footprint at the target range is required. Measurements conducted during 1983 utilized an available FM-CW radar system adapted so that its transmitted frequency swept over a wide band to produce a range resolution of about 11.0 cm. A focused parabolic-reflector antenna system was used to provide narrow beamwidths in both the azimuth and the elevation directions; this resulted in a footprint of 15 x 18 cm at the range of 4 m. Associated with this system were relatively high range-sidelobe levels which made target detection ambiguous at times. Therefore, funding for a specialized radar system was requested and approved. Consequently, a short-range very-fine resolution FM-CW radar system was designed and built. This radar system (SOURCESCAT) also provides a range resolution of 11 cm, but its range-sidelobe levels are appreciably reduced. The same focused antenna system used in 1983 was used with the SOURCESCAT.

Targets examined during the 1984 growing season included corn, soybeans, wheat, alfalfa, short grass, tall prairie bluegrass and several types of trees. To determine the main sources of backscattering in these targets, constituent defoliation (i.e., for corn and trees) and layer-by-layer defoliation (i.e., soybeans and tall grass) were implemented. All the measurements were conducted at incidence angles of 30° and 50°.

RESULTS

For an individual corn plant, backscattered energy is mainly due to the leaves; scattering from the cobs and the stalk is negligible, as shown in Figure 1. For a canopy, echoes from the upper 1 - 1.5 m portion of the plants dominate the total echo. Energy returned from the ground is insignificant due to the two-way attenuation of the radar signal through the canopy.

Soybeans are very lossy volume scatterers. The two-way loss through one row of plants ranges from 20 to 15 dB at 30° and 50°, respectively. Backscattered energy from the upper 30 cm of the plant dominates the returned signal. The energy returned from this portion is about the same at both incidence angles. Layer-by-layer defoliation indicates that the unattenuated backscattering from various leaves in the canopy is about the same.

The backscatter from wheat is dominated by the heads in both the early and late stages of the growth. Backscatter from heads remains almost constant at different stages, but attenuation through the heads is considerably more at the early stages of growth due to its higher moisture content at this stage. This shows backscatter insensitivity to moisture content but direct loss due to moisture content of the heads.

Individual alfalfa plants of about 40 cm tall were observed with no defoliation performed. In the presence of the plants, the returns due to the entire plants dominated the radar signal (individual parts of the alfalfa plants are too small to resolve). The returns in this case were slightly higher at 30° than at 50° incidence angles. With the plants removed, backscatter from the roots was observed at the depth of 5 to 12.5 cm beneath the ground.

Two different tall prairie grasses (50 cm high) were examined. The first site was an undisturbed and natural site which contained the dead grass material from the previous year on top of the soil. The second site had this dead material intentionally burnt off the soil before the growing season. Therefore, the latter site contained less soil moisture than the former site. The results of our measurements were also in agreement with this fact. In both cases, a volume of grass about 15 cm thick and about 25 cm above the soil gave the strongest backscattered energy. This experiment was conducted in collaboration with investigators from Kansas State University.

For pine trees, the needles showed the strongest backscatter, and caused the strongest attenuation in the radar signal. Cones, although insignificant contributors to the total backscatter, exhibited more backscattering than attenuation properties. Figure 2 illustrates these results.

Four types of deciduous trees were examined. Leaves were a strong cause of backscattering and attenuation. However, removing the leaves and keeping the leaftails and small twigs and branches reduced the backscattered energy very little. Therefore, their contribution to the total backscatter cannot be ignored.

These results are in great agreement with the results of the 1983 experiments, but there is more confidence in these results because a greater number of independent samples were observed and the ambiguities caused by range sidelobes were much less.

DISCUSSION

To obtain a complete understanding of the wave-target interaction process, experiments need to be conducted and models developed in each of the following areas:

(1) Target Dielectric Properties: To model a vegetation canopy, the dielectric constant of canopy constituents (leaves, stalks, fruits, etc.) as a function of temperature and water-volume fraction needs to be known.

(2) Target Attenuation Properties: For media such as snow, forests, and vegetation canopies, attenuation properties of the medium are essential in modeling.

(3) Target Volume Geometry: Methods need to be developed to measure the three-dimensional statistical distribution of orientation and density of scatterers within the volume.

(4) Target Scattering Properties: Extensive measurements need to be conducted on the scattering behavior of (a) targets under natural conditions, and (b) target constituents.

Information from all of these four areas enter into a scattering model. The existing scattering models in many cases assume or estimate the contribution of some of these parameters to the whole model. To develop complete models, these assumptions and estimations must very closely coincide with the true state of these parameters. This can only be achieved through sound experiments in the above areas.

By modeling the scattering properties of target constituents and using our experiment results to cross-check the models, we may be able to model correctly the scattering properties of the target as a whole.

A method-of-moments solution is proposed to compute the scattering from the individual plant parts, which may be modeled as dielectric cylinders, ellipsoids or smooth-curved dielectric slabs of arbitrary shapes. The analysis is based on the LeVine-Schwinger integro-differential equation, derived from the equivalent polarization current. The solution for the total field is obtained numerically. The far-zone approximation is applied to the integral equation. Given the total field inside the dielectric scatterer, we can calculate the scattered field and, therefore, the scattering cross-section.

More concentrated experiments and research in this area are needed to answer all the related questions raised and those that may be introduced as the research progresses. Experiments on more natural targets and man-made targets (such as buildings) will continue in 1985, along with extensive efforts on developing scattering models.

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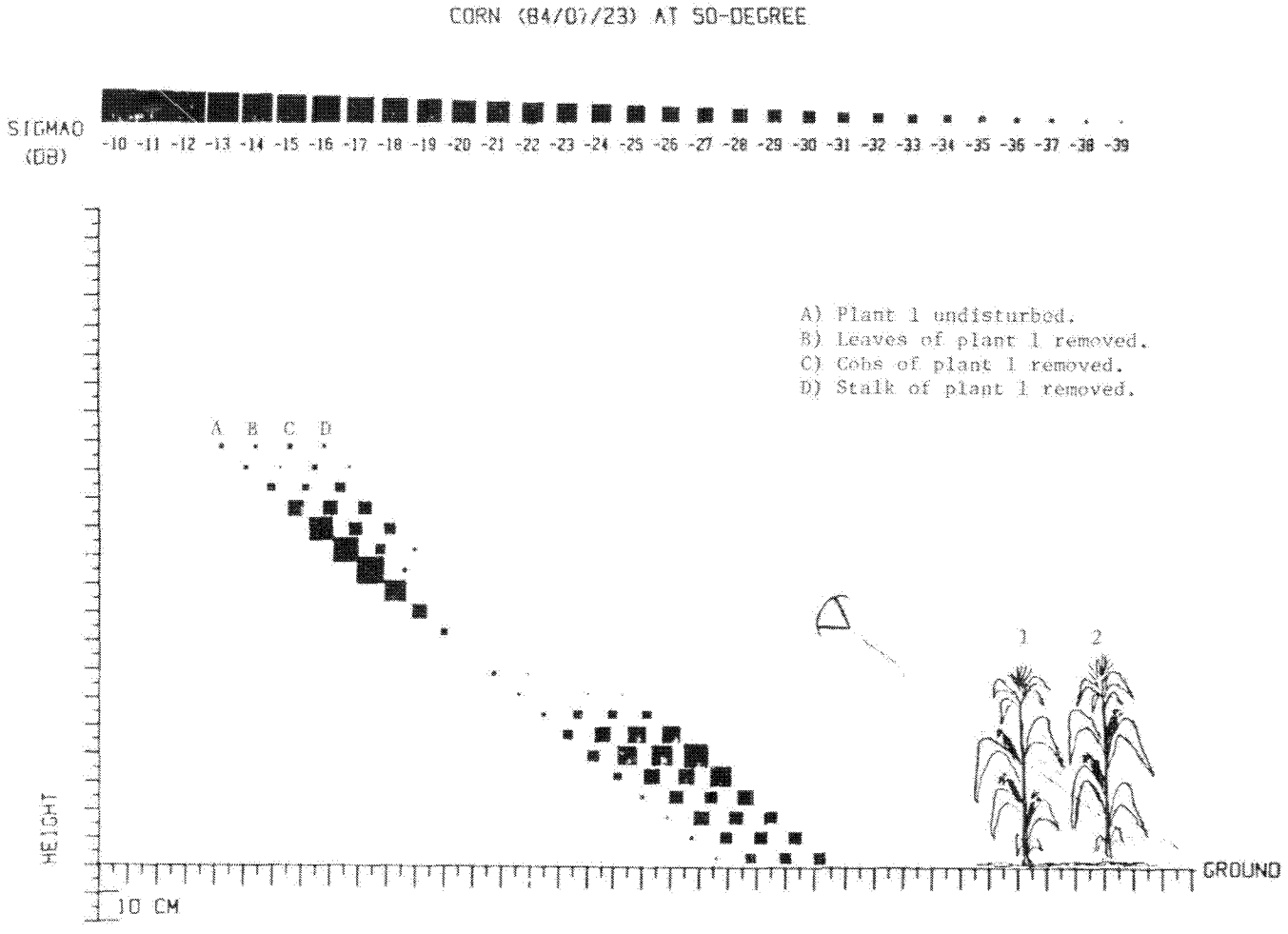
CORN (84/07/23) AT 50-DEGREE
SIGMA0 (DB)
-10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -22 -23 -24 -25 -26 -27 -28 -29 -30 -31 -32 -33 -34 -35 -36 -37 -38 -39
A) Plant 1 undisturbed.
B) Leaves of plant 1 removed.
C) Cobs of plant 1 removed.
D) Stalk of plant 1 removed.
A B C D
1 2
HEIGHT
GROUND
10 CM

Figure 1

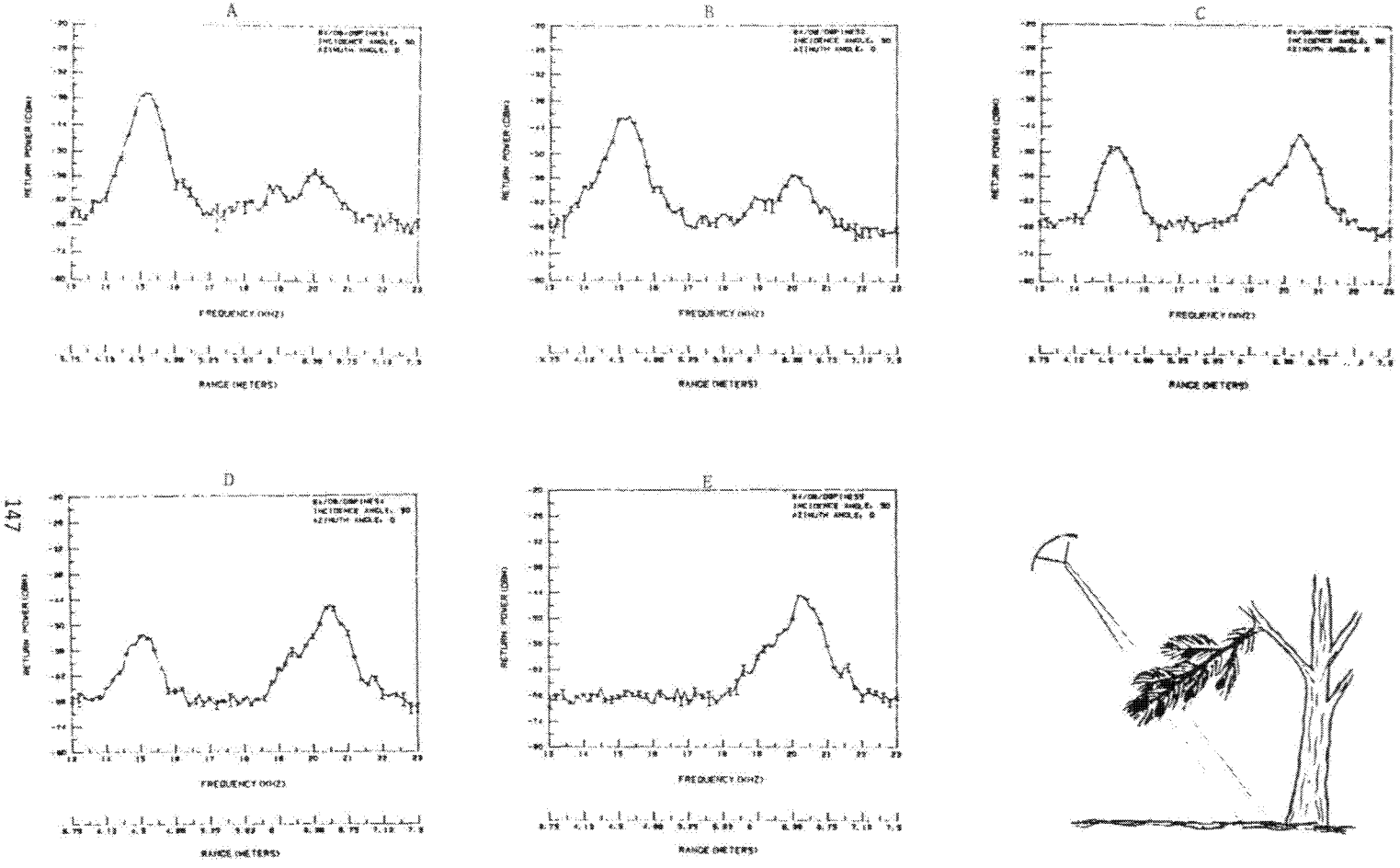

Figure 2: Pine Tree Results. First echo due to the branch, second echo due to the ground.
A) Undisturbed branch, B) Cones removed.
C) Pine needles removed, D) Small branches removed.
E) Main branch removed.

N86-13812

ACTIVE MICROWAVE PROPERITES OF VEGETATION CANOPIES

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Justification. Potential users of radar imagery need a better fundamental understanding of the capabilities of radar systems for vegetation studies than past studies provide. One approach is the use of theoretical models to predict observable active microwave properties of vegetation. This in turn requires accurate observations of backscattering coefficients and other active microwave properties in field research studies. The background document for the SRAEC program emphasizes the need to relate electromagnetic parameters to classical biophysical descriptors and to understand the role of polarization, especially cross-polarization. Goals. The broad goal of my study is to increase the understanding of the effects of canopy structure on the active micorwave properties of vegetation canopies, with particular attention to polarization.

Approach. In the first year, I studied aircraft radar scatterometer measurements of corn and soybean fields in Iowa to determine the properties of these mature fields at L-band (19 cm) and C-band (6 cm) and at sensor look-angles from 5 to 50 degress. In the second year, I used the Cloud Model (Ref. 1) with a set of X-band (3 cm) and K-band (2 cm) truck-based radar scatterometer like-polarization data for corn in Kansas to extend the model and to relate the model parameters to biophysical characteristics of the corn. For the third and current year, I used a C-band dual-polarization truck scatterometer at the University of California Kearney Agricultural Center to measure the active microwave properties of trees in orchards. Using the Cloud Model, I was able to estimate not only the backscattering coefficient, but also the attenuation coefficient, the density of backscattering cross sections, and the transmittance. The research activity lead to a new procedure in using such truck-based radar scatterometer data for thick, volume scattering media.

Results.

First Year. In the first year, I found that mature corn and soybean fields could be best separated with the use of C-band cross-polarization (HV) data at 50 degrees. No separation existed for C-band like-polarization (HH). At L-band, the separation of corn and soybeans was best for like-polarization (HH), but was not as good as it was for C-band HV data. No separation existed in L-band cross-polarization data. I observed significant row direction effects for sensor look-angle near 15 degrees when like-polarization was used. These effects were strongest at L-band. No row direction effects existed for cross-polarization for either band. Finally, I observed that the presence of wet soil and/or wet canopy due to rain reduced the separations of corn and soybeans and produced a significant increase in backscatter, especially near 15 degrees.

Second Year. In examining the Cloud Model, I found that the model form was significantly different for cross-polarization than it was for its usual like-polarization formulation. Also, I found that the use of the ratios of back-scattering coefficients for the various polarization combinations (VV, HH, HV and VH) could lead to the isolation of canopy angular orientation properties.

This allowed a new interpretation of the corn and soybean data studied in the first year. Similar separations existed in the depolarization ratio (cross-polarization divided by like-polarization) such as existed independently in the better of the two channels. Finally, by applying the Cloud Model to through-the-season, truck-based radar scatterometer measurements, I could estimate the backscattering and extinction cross sections of average leaves. I found that the former was a simple power-law function of corn leaf area (r^2 of 0.97) throughout the season.

Third Year. I used the Microwave Scatterometer C-band (MSC), on loan from the NASA Johnson Space Center, mounted on a JPL truck (height of 11 m) to make field measurements. This instrument obtains calibrated radar backscattering coefficient data in the field. However, it samples a volume that is limited in size due to the finite range-resolution and the finite beam-width. It obtains data at both like-polarization and cross-polarization. Through the use of the ranging capability of the MSC and the Cloud Model, I was able to estimate the active microwave properties of vegetation canopies, as follows: (1) the true, corrected backscattering coefficient, S^o_T; (2) the volume extinction coefficient K (m^{-1}); (3) the backscattering cross section density, E ($m^2\ m^{-3}$); (4) the two-way transmittance of the canopy, $t_i\ t_j$ (i and j stand for H or V to denote the polarization combination used); (5) the "full canopy" backscattering coefficient, S^o_{FC}; and (6) the distribution of sources with range. For a given vegetation canopy these active microwave characteristics vary with polarization or polarization combination.

Illustration of the New Procedure. The procedure to obtain these parameters is illustrated below for an ideal case where the canopy properties are homogeneous. One view of the Cloud Model is that the observed backscattering coefficient is given by

$$S^o = \int_{R_1}^{R_3} f\, dR = \int_{R_1}^{R_2} f_1\, dR + \int_{R_2}^{R_3} f_2\, dR \qquad (1)$$

for the one-layer case, where the canopy elements are found between the ranges, R_1 and R_2 (m), with the reflected (mirror image) canopy extending to range R_3 (m),

$$f_1 = E_{ij} \cos(T) \exp[-(K_i + K_j)(R - R_1)] \qquad (2)$$

$$f_2 = E_{ij}\, r_{ij} \cos(T) \exp[-(K_i + K_j)(R_2 - R_1)] \cdot \exp[-(K_i + K_j)(R - R_2)] \qquad (3)$$

where T is the sensor look-angle (degrees), r_{ij} is the surface reflectance (assumed to specular in basic character) for polarization ij, and R is the range (m).

The integration of Eq. (1) over the entire range from R_1 to R_3 with the expressions in (2) and (3) leads to the true canopy backscattering coefficient,

$$S^o_T = E_{ij} \cos(T)\,(1 + r_{ij}\, t_i\, t_j)\,(1 - t_i\, t_j) + t_i\, t_j\, S^o_{ijs} \qquad (4)$$

where S^o_{ijs} is the surface backscattering coefficient.

However, for the MSC (or any scatterometer having a small, finite range resolution), the sensor measures only a fraction of the total backscattering. I call this the partial backscattering coefficient (measured) which is related to the function f by

$$\Delta S^o = \int f\, dR \text{ (over the range resolution, } \Delta R) \qquad (5)$$

Since ΔR is small it is possible to estimate the function f by $\Delta S^o/\Delta R$.

Figure 1 shows the comparison between the given (true) value of f and the estimated value of f as obtained from a modeled prediction of the "measured" partial backscattering coefficient (see Figure 2). The estimated f is close to the given f for some ranges but not for all ranges. Now, it is possible to perform a numerical integration to estimate the true value of backscattering coefficient as indicated in Eq. (1) above. For thick vegetation canopies, the true value is significantly higher than the largest partial value. Thus, this procedure is required for such situations.

Since the variation of f with range is a decaying exponential function, the use of the logarithm of f (or alternatively, expression of f in deciBels, dB) leads to a straight line portion of the f (dB) versus R curve (see Figure 3). Passing a straight line through points in this segment allows estimation of both E and K by

$$E = f_{R_1} \sec(T) \quad \text{and} \quad K = \text{slope}/(-8.686) \qquad (6) \text{ and } (7)$$

With the estimated value of K and the known slant range thickness of the canopy, $t_i\, t_j$ can be estimated. Using rough estimates of r and surface backscattering coefficient, one can estimate independently the value for E. This value should be close to that estimated for Eq. (6). With the new values for E and K it is possible to estimate the "full canopy" backscattering coefficient from

$$S^o_{FC} = E \cos(T)/(K_i + K_j) \qquad (8)$$

If the second (reflected) portion of the f (dB) versus R curve can be detected, it is possible to extrapolate the two straight lines (one from ranges less than the range to the surface, and one for ranges greater than the range to the surface) to the surface range values of f_L (left side) and f_R (right side) and

calculate r by f_R/f_L. Since the estimated value of f at R_2 may be higher than the average value of f_L and f_R due to the contribution of attentuated surface backscattering, it is possible to estimate the surface backscattering coefficient.

Results with Orchards. Figure 4 shows the partial backscattering coefficients versus range for a young peach orchard (see Figure 5 which indicates the tree structure). Note that near the top of the canopy the radar return is dominated by the VV where HH dominates the return near the base of the canopy. After the noise floor is estimated and subtracted, the data were used to estimate f (dB) as shown in Figure 6. The active radar parameters shown in Table 1 are obtained from these data using the above procedure.

Significance of Results. The three year study shows that, in many cases, cross-polarization or a combination of HH, VV and/or cross-polarization yeilds information on the angular orientation of vegetation canopies. Ratios of channels should be used to isolate such information from other vegetation characteristics such as total areal biomass or water content. Furthermore, with the proper use of simple microwave scattering models, such as the Cloud Model, and accurate radar scatterometer data, it is possible to esitmate the total backscattering coefficient, the attentuation coefficient, the transmittance, and average scattering and extinction radar cross sections of scattering elements. These data should prove useful for verification of modeling approaches and for the development of adequate understanding of the information content of radar sensor data such as from the synthetic aperture radar (SAR) imagers.

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1. Attema, E.P.W. and F.T. Ulaby, 1978: Vegetation modeled as a water cloud. Radio Sci. 13(2):357-364.

Table 1.

Example of Measured Active Microwave Properties of Orchards Through Analysis of Truck Radar Scatterometer Measurements at C-Band and 60 Degrees

Field	Pol	ΔS^o_{max}	S^o_T (dB)	E (m^{-1})	K (m^{-1})	t_2	S^o_{FC} (dB)
Mature	VV		-10.2	0.077	0.199	0.021	-10.1
Peach	HH		-11.6	0.050	0.178	0.031	-11.5
Orchard	VH		-17.3	0.014	0.188	0.026	-17.2
Young	VV		-10.4	0.036	0.082	0.203	- 9.6
Peach	HH		-12.1	0.028	0.087	0.286	-11.0
Orchard	VH		-15.8	0.011	0.084	0.241	-15.1

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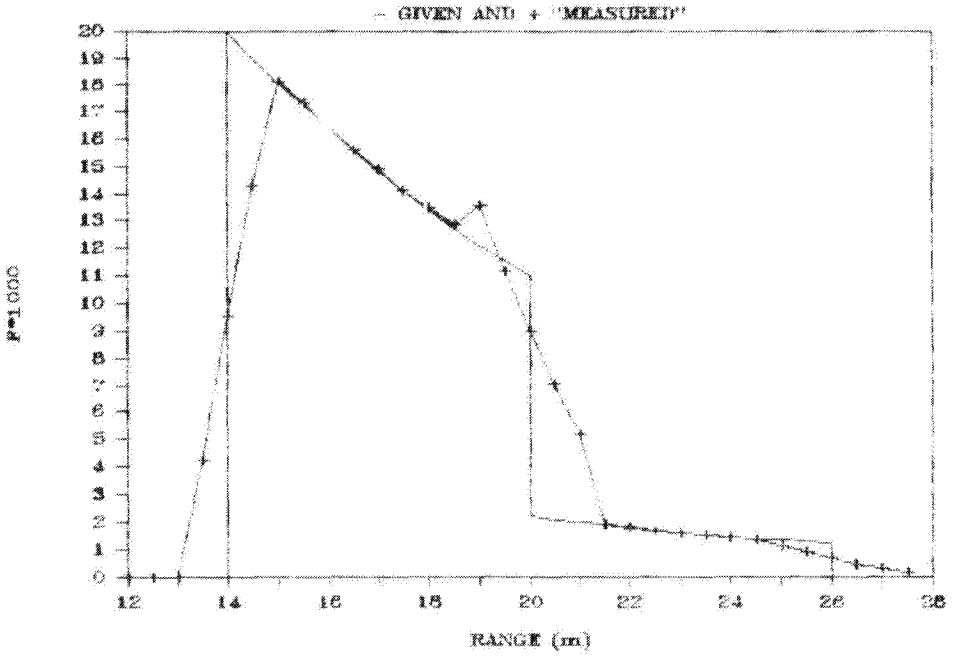

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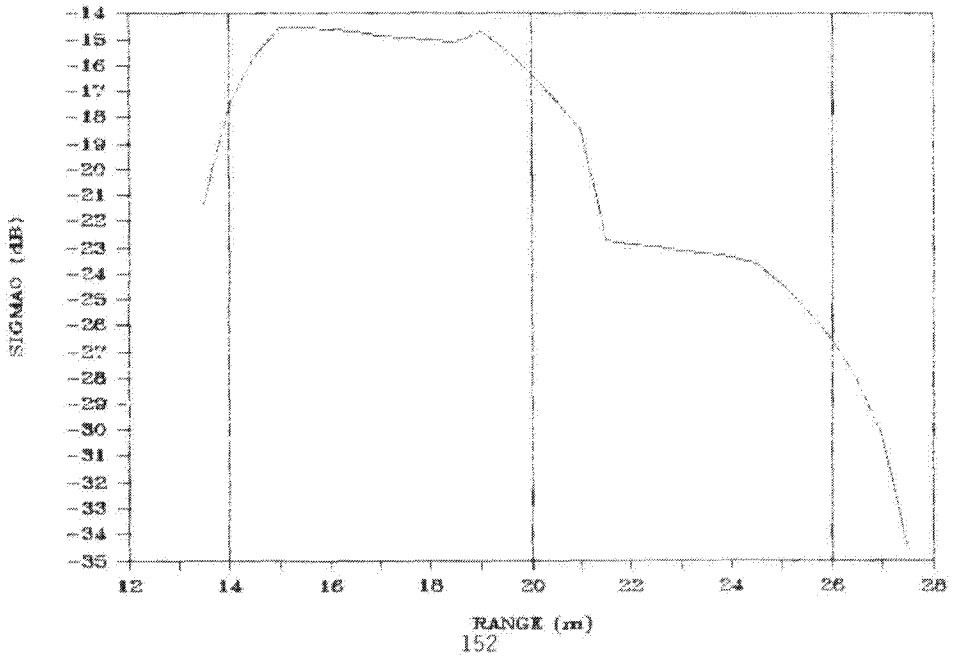

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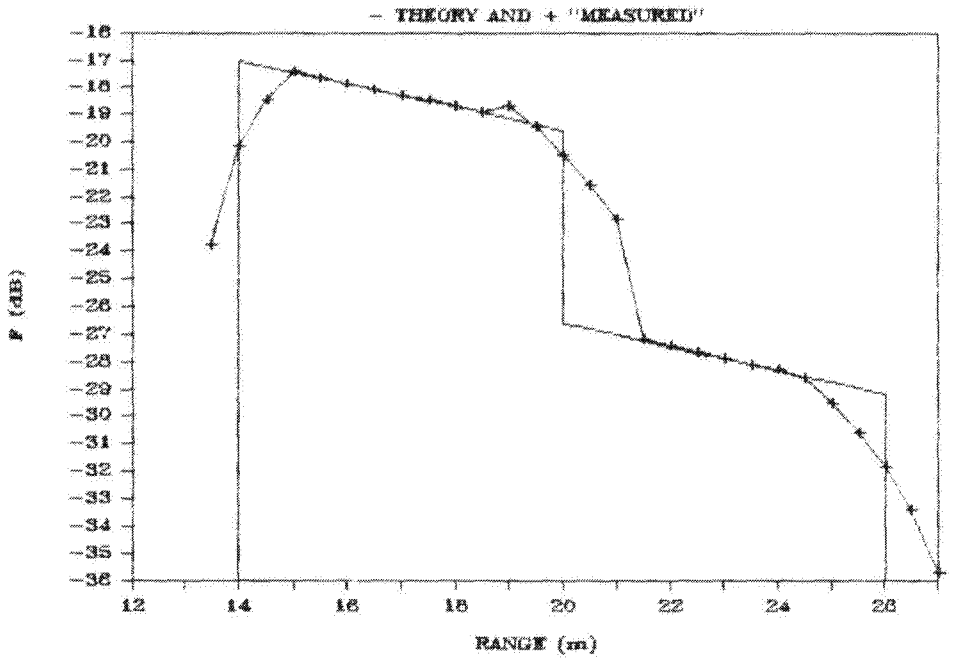

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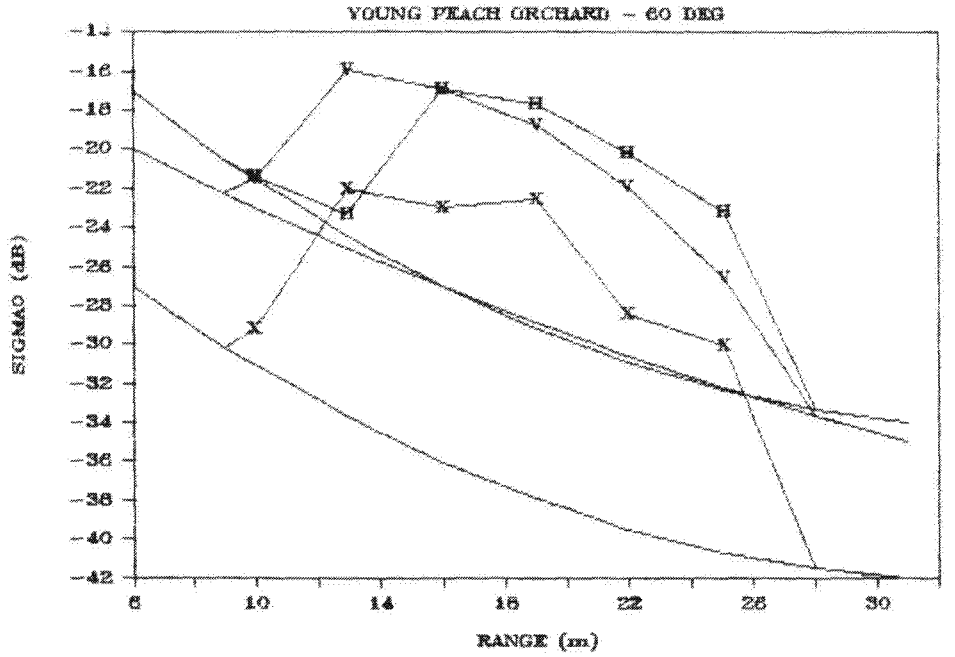
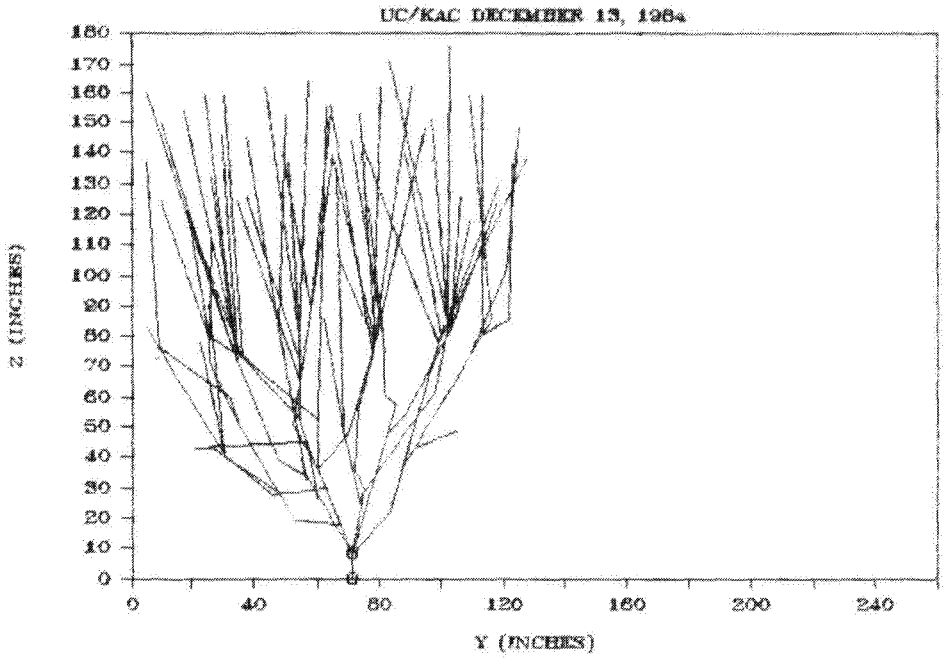


YOUNG PEACH TREE STRUCTURE



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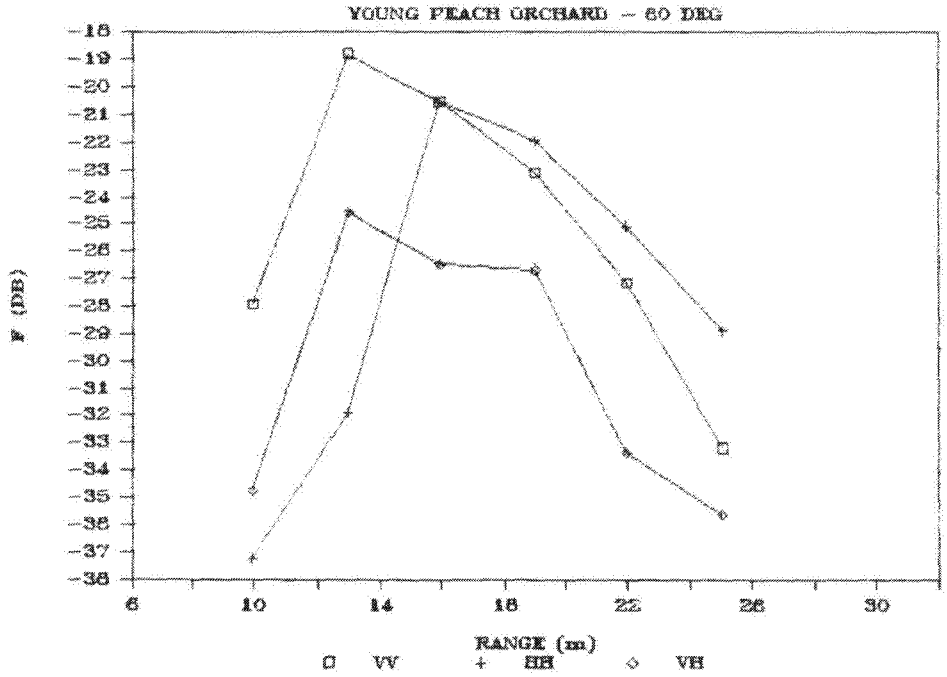

II.C. LIST OF PUBLICATIONS AND PRESENTATIONS

The following pages list the refereed journal articles and other publications and presentations that report on the results of the research performed under the SRAEC Project. The listings are presented as provided by the principal investigators and are arranged in the same order as the summary reports presented in Section II.B.

SRAEC Project scientists have produced approximately 80 refereed scientific journal papers during the first three years of the program as well as dozens of additional writings in the form of theses, dissertations, symposium and conference proceedings, and special documents.

REFLECTANCE MODELING

Dr. James A. Smith

Refereed Publications

M. H. Randolph and J. A. Smith. 1985. A RTE Phase Function Description of Vegetation Canopies. (Submitted to IEEE Trans. Geosci. & Rem. Sens.)

K. D. Cooper and J. A. Smith. A Monte-Carlo Reflectance Model for Complex Soil Surfaces. 1985. (Submitted to IEEE Trans. Geosci. & Rem. Sens.)

A. H. Strahler, C. E. Woodcock, and J. A. Smith. On the Nature of Models in Remote Sensing. 1985. (Submitted to IEEE Trans. Geosci. & Rem. Sens.)

Published Proceedings

P. M. Teillet, R. Brown, J. A. Smith, and G. Federejeus. 1983. Reflectance Model Studies at the CCRS. Intl. Coloq. on Spectral Sign. in Rem. Sens. Bordeau, France.

J. A. Smith, K. D. Cooper, and A. H. Strahler. 1984. Electro-optical Terrain Reflectance Modeling: Some Perspectives. Proc. SPIE Spring Meetings, Wash. D. C., 475: 12-17. (Invited paper for Critical Reviews of Technology Series in Remote Sensing)

BIDIRECTIONAL REFLECTANCE MODELING OF NON-HOMOGENEOUS PLANT CANOPIES

John M. Norman
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Publications

Norman, J. M. and J. W. Welles. 1983. Radiative transfer in an array of canopies. Agron. J. 75:481-488.

Walthall, C. L., J. M. Norman, J. M. Welles, G. Campbell and B. L. Blad. 1985. A simple equation to approximate the bidirectional reflectance from vegetated surfaces. Appl. Optics. (to be published Feb. 1985).

Norman, J. M., J. M. Welles and E. A. Walter. 1985. Contrasts among bidirectional reflectance of leaves, canopies and soils. IEEE Trans. GeoSci. Remote Sensing. Submitted.

Kimes, D. S., J. M. Norman and C. L. Walthall. 1985. Modeling the radiant transfers of sparse vegetation canopies. IEEE Trans. GeoSci. Remote Sensing. Submitted.

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Norman, J. M. 1984. Using canopy reflectance properties to estimate some parameters essential to macroscale Et predictions. Amer. Geophys. Union Abstracts, Fall, 1985. AGU, Washington, D. C.

Norman, J. M., J. M. Welles, E. A. Walter and G. S. Campbell. 1984. A bidirectional reflectance model for heterogeneous plant canopies. Amer. Soc. Agron. Abstracts, Madison, WIS. 53706. p. 15.

Walter, E. A., J. M. Norman, J. M. Welles and B. L. Blad. 1984. Leaf bidirectional reflectance measurements in corn and soybean. Amer. Soc. Agron. Abstracts, Madison, WIS. 53706. p. 19.

Presentations

1982 Volunteer paper - The effect of pubescence on soybean leaf and canopy reflectance. Amer. Soc. Agron. Annual Meeting, Anaheim, CA., Nov. 28-Dec. 3.

1984 Invited paper - Using canopy reflectance properties to estimate some parameters essential to macroscale Et predictions. Hydrology Symposium on Evapotranspiration Modeling, Fall Amer. Geophys. Union Meeting, San Francisco, CA, Dec. 3-7.

1984 Volunteer paper - A bidirectional reflectance model for heterogeneous plant canopies. Amer. Soc. Agron. Annual Meeting, Las Vegas, NEV., Nov. 25-30.

1984 Invited to present research results at Fundamental Research Project Briefing at NASA Headquarters for Dr. Shelby Tilford and Dr. Burton Edelson, Washington, D. C. Mar. 16.

1984 Invited seminar - Bidirectional reflectance in heterogeneous plant canopies. Monthly seminar series jointly sponsored by U. of Maryland RSSL and NASA/GSFC, Washington, D.C. July 19.

Understanding the Radiant Scattering Behavior of Vegetated Scenes

Daniel S. Kimes

1) Refereed Journal Publications

Kimes, D.S. and J.A. Kirchner, 1982, "Irradiance Measurement Errors Due to the Assumption of a Lambertian Reference Panel," Remote Sensing of Environment, 12:141-149

Kimes, D.S and J.A. Kirchner, 1982, "Radiative Transfer Model for Heterogeneous 3-D Scenes," Applied Optics, 21(22):4119-4129.

Kimes D.S. and J.A. Kirchner and J.E. McMurtrey III, 1982, "Variation of Directional Reflectance Factors with Structural Changes of a Developing Alfalfa Canopy," Applied Optics, 22:3766-3774.

Kimes, D.S. and J.A. Kirchner, 1983, "Directional Radiometric Measurements of Row-Crop Temperatures," Int. J. Remote Sensing, 4(2):299-311.

Kimes, D.S., 1983, "Remote Sensing of Row Crop Structure and Component Temperatures Using Directional Radiometric Temperatures and Inversion Techniques," Remote Sensing of Environment, 13:33-55.

Kimes, D.S. and J.A. Kirchner, 1983, "Diurnal Variations of Vegetation Canopy Structure," Int. J. Remote Sensing, 4(2):257-271.

Kimes, D.S., 1983, "Dynamics of Directional Reflectance Factor Distributions for Vegetation Canopies," Applied Optics, 22:1364-1372.

Kimes, D.S., J.A. Kirchner and W.W. Newcomb, 1983, "Spectral Radiance Errors in Remote Sensing Ground Studies Due to Near by Objects," Applied Optics, 22:8-10.

Kimes, D.S., B.N. Holben, C.J. Tucker and W.W. Newcomb, "Optimal Directional View Angles for Remote Sensing Missions," Int. J. Remote Sensing, 5:887-908.

Kimes, D.S., W.W. Newcomb, J.B. Schutt, P.J. Pinter, Jr., and R.D. Jackson, "Directional reflectance factor distributions of a cotton row crops," Int. J. of Remote Sensing, 5:263-277.

Kimes, D.S., "Modeling the Directional Reflectance from Complete Homgeneous Vegetation Canopies with Various Leaf Orientation Distribution," Journal of the Optical Society of America, 1:725-737.

Kimes, D.S., W.W. Newcomb, C.J. Tucker, I.S. Zonneveld, W. Van Wijngaarden, G.F. Epema, and J. DeLeeun, "Directional Reflectance Factor Distributions for Cover Types of Northern Africa in NOAA 7/8 AVHRR Bands 1 and 2," Remote Sensing of Environment, in press.

Kimes, D.S., J.M. Norman, and C.L. Walthall, 1985, "Modeling the Radiant Transfers of Sparse Vegetation Canopies," IEEE Transaction on Geoscience and Remote Sensing, submitted.

MEASUREMENTS AND MODELING OF THE OPTICAL SCATTERING PROPERTIES OF CROP CANOPIES

V. C. Vanderbilt

Publications

Refereed Journal Publications

Vanderbilt, V.C., L. Grant, and C.S.T. Daughtry, "Polarization of light scattered by vegetation," Proceedings IEEE, (in press).

Vanderbilt, V.C. and L. Grant, "Plant canopy specular reflectance model," (submitted to IEEE Transactions on Geoscience Electronics and Remote Sensing).

Vanderbilt, V.C., L. Grant, L.L. Biehl, and B.F. Robinson, "Specular, diffuse and polarized light scattered by two wheat canopies," (Accepted by Applied Optics.

Vanderbilt, V.C., "Measuring plant canopy structure," (submitted to Photogrammetric Engineering and Remote Sensing).

Conference Presentations

Vanderbilt, V.C. and L. Grant, "Light polarization measurements: a method to determine the specular and diffuse light-scattering properties of both leaves and plant canopies," Conference paper presented to the International Colloquium on Spectral Signatures of Objects in Remote sensing, September 1983, Bordeaux, France. LARS Technical Report 091683.

Grant, L., V.C. Vanderbilt, and C.S.T. Daughtry, "Measurements of specularly reflected radiation for individual leaves," Agronomy Abstracts, vol. 75, p. 12, 1983.

Vanderbilt, V.C., L. Grant, L.L. Biehl, and B.F. Robinson, "Specular and diffuse reflectance of two wheat canopies measured at many view angles," (Abstract) International Union of Radio Science. January 1983.

GEOMETRIC-OPTICAL MODELING OF A CONIFER FOREST CANOPY

Alan H. Strahler
Hunter College

List of Publications

Journal Articles:

Franklin, Janet, J. Michaelson, and A. H. Strahler, 1985. Spatial pattern in coniferous forest stands. Vegetatio, submitted. 29 ms. pp. + 7 fig. + 3 tab.

Li, Xiaowen, and A. H. Strahler, 1985. Geometric-optical modeling of a conifer forest canopy. IEEE Trans. on Geoscience and Remote Sensing, submitted. 54 ms. pp. + 16 fig. + 4 tab.

Strahler, Alan H., C. E. Woodcock, and J. A. Smith, 1985. On the nature of models in remote sensing. IEEE Trans. on Geoscience and Remote Sensing, submitted. 42 ms. pp.

Proceedings Papers:

Smith, J. A., K. D. Cooper, and A. H. Strahler, 1984. Electro-optical terrain reflectance modeling: A perspective. Proc. SPIE Tech. Symp., Spr. 1984, pp. 12-17.

Strahler, Alan H., X. Li and J. Franklin, 1985. Spatial/spectral modeling of conifer forest canopies. Modeling and Simulation, Volume 15, Proc. Fifteenth Ann. Pittsburgh Conf. on Modeling and Simulation, April 19-20, 1984, pp. 19-21.

Strahler, Alan H., C. E. Woodcock, X. Li, and D. L. B. Jupp, 1984. Discrete-object modeling of remotely sensed scenes. Proc. Eighteenth Int. Symp. on Remote Sensing of Environment, Paris, France, Oct. 1-5, 1894, in press, 10 pp.

Strahler, Alan H. and X. Li, 1984. Spatial/spectral modeling of conifer forest reflectance. Proc. Third Australasian Remote Sensing Conf., Gold Coast, Queensland, Australia, May 21-25, 1984, pp. 88-90.

Geometric-optical Modeling

Theses and Dissertations:

Franklin, Janet, 1983. An Empirical Study of the Spatial Pattern of Coniferous Trees. M. A. Thesis, Univ. of California, Santa Barbara, June 1983, 99 pp.

Li, Xiaowen, 1985. Geometric-Optical Modeling of a Coniferous Forest Canopy. Ph. D. Dissert., Univ. of California, Santa Barbara, March 1985, 78 pp.

CROP CHARACTERISTIC RESEARCH:
GROWTH AND REFLECTANCE ANALYSIS

G. D. Badhwar
Johnson Space Center
Houston, TX 77058

PUBLICATIONS

Journal Articles

1. G. D. Badhwar, W. Verhoef, and N. J. J. Bunnik: Comparative Study of Suits and SAIL Canopy Reflectance Models, Remote Sensing of Environment, vol 17, 1985.

2. E. Reyna and G. D. Badhwar: Inclusion of Specular Reflectance in Canopy Models: IEEE Geoscience and Remote Sensing, 1985.

3. G. D. Badhwar: Multitemporal Classification of Corn and Soybeans Using Thematic Mapper Data: Remote Sensing of Environment, vol 16, pp 175-182 (1984).

4. G. D. Badhwar and K. E. Henderson: Application of TM and Simulated TM Data to Estimate the Development Stages of Corn and Soybeans: Remote Sensing of Environment, vol 17 (1985).

5. G. D. Badhwar and K. E. Henderson: Relationship of Profile Inflection Points to Crop Development Stage and Yield: Agronomy Journal, 1985.

SYMPOSIA

1. G. D. Badhwar and S. S. Shen: Techniques for the Estimation of Leaf Area Index Using Spectral Data: 10th International Symposium on Machine Processing of Remotely Sensed Data, June 12-14, 1982.

2. G. D. Badhwar, R. B. MacDonald, F. G. Hall, and J. G. Carnes: Spectral Characterization of Biophysical Characteristics in a Boreal Forest: Relationship Between Thematic Mapper. Band Reflectance and Leaf Area Index for Aspen: Proceedings of IGARSS'84 Symposium, August 27-30, 1984, pp 111-115.

A member of AgRISTARS documents describing the data produced.

ATMOSPHERIC AND SCENE COMPLEXITY EFFECTS ON SURFACE BIDIRECTIONAL REFLECTANCE

David J. Diner (Principal Investigator)

Refereed Journal Publications

1. Diner, D. J. and Martonchik, J. V. (1984). Atmospheric transfer of radiation above an inhomogeneous non-Lambertian reflective ground. I. Theory. J. Quant. Spectr. Rad. Transf. 31, 97-125.

2. Diner, D. J. and Martonchik, J. V. (1984). Atmospheric transfer of radiation above an inhomogeneous non-Lambertian reflective ground. II. Computational considerations and results. J. Quant. Spectr. Rad. Transf. 32, 279-304.

3. Martonchik, J. V. and Diner, D. J. (1985). Three-dimensional radiative transfer using a Fourier transform matrix operator method. J. Quant. Spectr. Rad. Transf., in press.

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1. Diner, D. J. (1983). Atmospheric influence upon observation of surface bidirectional refletances. National Radio Science Meeting, Boulder, CO.

2. Diner, D. J. and Martonchik, J. V. (1983). Atmospheric radiative transfer above a surface of nonuniform albedo: The planetary problem in 3-D. 15th Annual American Astronomical Society, Division for Planetary Sciences Meeting, Ithaca, NY.

3. Diner, D. J. and Martonchik, J. V. (1985). Remote sensing of atmospheric opacity using multiple view angle imaging. Optical Society of America Meeting on Optical Remote Sensing of the Atmosphere, Incline Village, NV.

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Robert S. Fraser - Principal Investigator
Yoram J. Kaufman - Co-investigator

Referred Journal Publications

1. Y. J. Kaufman, 'Solution of the equation of radiative transfer for remote sensing over two-dimensional surface reflectivity', J. Geoph. Res., 20, 4137-4147, 1982.

2. Y. Mekler and Y. J. Kaufman, 'Contrast reduction by the atmosphere and retreival of nonuniform surface reflectance', Applied Optics, 21, 310-316, 1982.

3. Y. J. Kaufman and R. S. Fraser, 'The effect of finite field size on classification and atmospheric correction', Remote Sensing of Environment, 15, 95-118, 1984.

4. Y. J. Kaufman and R. S. Fraser, 'Different atmospheric effects in remote sensing of uniform and nonuniform surfaces', Adv. Space Res. Vol. 2, pp. 147-155, 1983.

5. Y. J. Kaufman, 'Atmospheric effect on spatial resolution of surface imagery', Applied Optics, 23, 3400-3408, 1984.

6. Yu. Mekler, Y. J. Kaufman and R. S. Fraser 'Reflectivity of the atmosphere-inhomogeneous surfaces system. Laboratory simulation.' J. Atmos. Sci., 41, 2595-2604, 1984.

7. Y. J. Kaufman, 'The atmospheric effect on separability of field classes measured from satellite', accepted for publication in Remote Sensing of Environment, 1984.

8. Y. J. Kaufman, T. W. Brakke and E. Eloranta 1985, 'Field experiment to measure the radiative characteristics of a hazy atmosphere', in preparation.

9. R. S. Fraser and Y. J. Kaufman 1985, 'The relative importance of aerosol scattering and absorption in remote sensing', submitted for publication in IEEE Transactions on Geoscience and Remote Sensing.

Symposium and Conference Presentations

10. Y. J. Kaufman and R. S. Fraser, 'Different atmospheric effects in remote sensing of uniform and nonuniform surfaces,' paper presented at the COSPAR 24th Planetary meeting, Ottawa, Canada, 1982.

11. Y. J. Kaufman, 'Atmospheric effects on spatial resolution and classification of surface imagery', paper presented at the 21st Aerospace Sciences Meeting, Reno, Nevada. 1983.

12. R. S. Fraser and Y. J. Kaufman, 'The relative importance of aerosol scattering and absorption in remote sensing', V Conf. on Atm. Radiation, Baltimore, MD, 1983.

13. Y. J. Kaufman, 'Atmospheric effects on remote sensing of surface reflectance,' Paper presented at the SPIE Crytical Review of Remote Sensing, Crystal City, Virginia, 1984.

14. Y. J. Kaufman, T. W. Brakke and E. Eloranta, 'Field experiment to measure the radiative characteristics of a hazy atmosphere', V. Conf. on Atm. Radiation, Baltimore, MD, 1983.

PUBLICATIONS

William A. Pearce

William A. Pearce, "Monte Carlo Study of the Atmospheric Spread Function," submitted to Applied Optics.

William A. Pearce, "Cloud Shadow Effects on Remote Sensing," submitted to IEEE Transactions on Geoscience and Remote Sensing.

MULTIDIMENSIONAL MODELING OF ATMOSPHERIC EFFECTS
AND SURFACE HETEROGENEITIES ON REMOTE SENSING

PI: S.A.W. Gerstl

A. Refereed Journal Publications

1. S.A.W. Gerstl and A. Zardecki, "Discrete-ordinates finite-element method for atmospheric radiative transfer and remote sensing," Appl. Opt. 24, 81-93 (1985).

2. S.A.W. Gerstl and A. Zardecki, "Coupled atmosphere/canopy model for remote sensing of plant reflectance features," Appl. Opt. 24, 94-103 (1985)

3. C. Simmer and S.A.W. Gerstl, "Remote Sensing of Angular Characteristics of Canopy Reflectances," submitted to IEEE Transactions, Special Issue, to appear Sept. 1985. Also, Los Alamos National Laboratory report LA-UR-85-31 (Jan. 1985).

4. A. Zardecki, S.A.W. Gerstl, and J.F. Embury, "Multiple scattering effects in spatial frequency filtering," Appl. Opt. 23, 4124-4131 (1984).

5. A. Zardecki, S.A.W. Gerstl, W.G. Tam, and J.F. Embury, "Image quality degradation in a turbid medium under partially coherent illumination," J. Opt. Soc. Am., accepted for publ. Dec. 1984.

B. Symposia and Conference Presentations

1. C. Simmer and S.A.W. Gerstl, "Influence of the Atmosphere on Remotely Sensed Reflection From Vegetation Surfaces," Topical Mtg. on Opt. Remote Sensing of the Atmosphere, Lake Tahoe, NV, January 14-18, 1985.

2. C. Simmer and S.A.W. Gerstl, "Modelled Atmospheric Effects on Remotely Sensed Bidirectional Reflection Distribution Functions (BRDFs)," Am. Geophys. Union 1984 Fall Mtg., San Francisco, CA, December 5-7, 1984.

3. A. Zardecki and S.A.W. Gerstl, "Modulation Transfer Functions Computed with Multiple Scattering Radiative Transfer Theory," 12th Int. Laser Radar Conf., Aix-en-Province, France, August 13-17, 1984.

4. S.A.W. Gerstl, A. Zardecki, and J.F. Embury, "Image Degradation and MTF Computation for Turbid Atmospheres," 1984 Annual Mtg. Opt. Soc. Am., San Diego, CA, October 1984.

5. S.A.W. Gerstl, "Atmospheric Effects in Satellite-Sensed Vegetative Surface Features," Assoc. Nat'l. Radio Science. Mtg. (URSI), Nat'l. Acad. Sci. and Eng. and Nat'l. Res. Council of the U.S., Bouldar, CO, January 5-7, 1983.

4. List of Publications

Lee,K.K., Scattering from an inhomogeneous layer, PhD. dissertation, Electrical Engineering Department, University of Kansas, Lawrence, Ks.66045. August, 1984.

Pan,G.W., The integral equation method for rough surface scattering, PhD. dissertation, Electrical Engineering Department, University of Kansas, Lawrence, Ks.66045. August, 1984.

Fung, A.K.,and H.J. Eom, Estimation of albedo and optical thickness with the radiative transfer method, IGARSS,84, Strasbourg, France. August, 1984.

Eom,H.J.and A.K.Fung, Backscattering coefficient of a perturbed sinusoidal surface, IEEE Trans. Ant. and Prop. vol. 32, no.3 pp.291-295, March 1984.

Fung,A.K. and H.J.Eom, A study of backscattering and emission from closely packed inhomogeneous media, National Radio Science Meeting, Boston,Mass. June 1984

REMOTE SENSING OF EARTH TERRAIN

Principal Investigator: Jin Au Kong

Refereed Journal Articles

A1. Passive and active remote sensing of atmospheric precipitation (Y. Q. Jin and J. A. Kong), Applied Optics, vol.22, 2535–2545, September 1983.

A2. Dyadic Green's functions for layered anisotropic medium (J. K. Lee and J. A. Kong), Electromagnetics, vol.3, 111–130, 1983.

A3. Wave scattering and guidance by dielectric waveguides with periodic surface (S. L. Chuang and J. A. Kong), Journal of the Optical Society of America, vol.73, 669–679, May 1983.

A4. Scattering of electromagnetic waves from a half-space of densely distributed dielectric scatterers (L. Tsang and J. A. Kong), Radio Science, vol.18, 1260–1272, Nov–Dec. 1983.

A5. Strong fluctuation theory for electromagnetic wave scattering by a layer of random discrete scatterers (Y. Q. Jin and J. A. Kong), Journal of Applied Physics, vol.55, 1364–1369, March 1984.

A6. Microwave thermal emission of periodic surface (J. A. Kong, S. L. Lin, and S. L. Chuang), IEEE Transactions on Geoscience and Remote Sensing, vol. GE-22, 377–382, July 1984.

A7. Scattering of electromagnetic waves from a randomly perturbed quasiperiodic surface (R. T. Shin and J. A. Kong), Journal of Applied Physics, vol.56, 10–21, July 1984.

A8. Radiative transfer theory for active remote sensing of a layer of nonspherical particles (L. Tsang, J. A. Kong, and R. T. Shin), Radio Science, vol.19, 629–642, March–April 1984.

A9. Ladder and cross terms in second order distorted Born approximation (Y. Q. Jin and J. A. Kong), J. Mathematical Physics, accepted for publication.

A10. Wave approach to brightness temperature from a bounded layer of random discrete scatterers (Y. Q. Jin), Electromagnetics, accepted for publication.

A11. Active microwave remote sensing of an anisotropic random layer (J. K. Lee and J. A. Kong), IEEE Transactions on Geoscience and Remote Sensing, submitted for publication.

A12. Passive microwave remote sensing of an anisotropic random medium layer (J. K. Lee and J. A. Kong), IEEE Transcations on Geoscience and Remote Sensing, submitted for publication.

Conference Articles

C1. Theoretical models for microwave remote sensing of vegetation and soil moisture (J. A. Kong), AgRISTARS Symposium, Houston, Texas, December 1-2, 1982.

C2. Thermal microwave emission from a scattering medium with rough surfaces (R. Shin and J. A. Kong), URSI Symposium, Boulder, Colorado, January 5-7, 1983.

C3. Remote sensing of soil moisture and vegetation (J. A. Kong, S. L. Lin, S. L. Chuang, and R. T. Shin), URSI Symposium, Boulder, Colorado, January 5-7, 1983.

C4. Mie scattering of electromagnetic waves by precipitation (Y. Q. Jin and J. A. Kong), Optical Society of America Topical Meeting on Optical Techniques for Remote Probing of the Atmosphere, Lake Tahoe, Nevada, January 10-12, 1983.

C5. Scattering of electromagnetic waves from a half-space of densely distributed dielectric scatterers (L. Tsang and J. A. Kong), IEEE/APS Symposium and URSI Meeting, Houston, Texas, May 23-26, 1983.

C6. Theory of microwave remote sensing of dense medium (L. Tsang and J. A. Kong), URSI Symposium, San Francisco, 1983.

C7. Wave scattering by a bounded layer of random discrete scatterers (Y. Q. Jin and J. A. Kong), National Radio Science Meeting, Boulder, Colorado, January 11-13, 1984.

C8. Scattering of electromagnetic waves by a randomly perturbed quasi-periodic surface (R. T. Shin and J. A. Kong),National Radio Science Meeting, Boston, Massachusetts, June 25-28, 1984.

C9. Modified radiative transfer equation in strong fluctuation approach (Y. Q. Jin and J. A. Kong), National Radio Science Meeting, Boston, Massachusetts, June 25-28, 1984.

C10. Active and passive microwave remote sensing of layered anisotropic random medium (J. K. Lee and J. A. Kong), National Radio Science Meeting, Boston, Massachusetts, June 25-28, 1984.

C11. Strong fluctuation theory of random medium and applications in remote sensing (Y. Q. Jin and J. A. Kong), International Symposium on Antennas and EM Theory (ISAE), Beijing, China, August 24-26, 1985.

Reports and Theses

R1. Emissivity of a two-layer random medium with anisotropic correlation function, (R. T. Shin and J. A. Kong), Technical Report No. EWT-RS-41-8303, MIT, 1983.

R2. Estimation of snow depth with measured brightness temperatures (H. Z. Wang), Technical Report No. EWT-RS-43-8304, MIT, 1983.

R3. Estimation of snow depth from backscattering cross section obtained from active microwave remote sensing (H. Wang), Technical Report No. EWT-RS-45-8306, MIT, 1983.

R4. Extended boundary condition approach to wave scattering by periodic structures (S. L. Chuang and J. A. Kong), Technical Report No. EWT-RS-55-8312, MIT, 1983.

R5. Microwave remote sensing of a scattering medium with rough surfaces (R. T. Shin and J. A. Kong), Technical Report No. EWT-RS-64-8402, MIT, 1984.

R6. Modified radiative transfer equation in strong fluctuation approach (Y. Q. Jin and J. A. Kong), Technical Report No. EWT-RS-67-8406, MIT, 1984.

R7. Active microwave remote Sensing of an anisotropic random medium layer (J. K. Lee and J. A. Kong), Technical Report No. EWT-RS-68-8407, MIT, 1984.

R8. Behavior of circularly polarized waves in active remote sensing of two-layer random media (F. C. Lin), Technical Report No. EWT-RS-70-8410, MIT, 1984.

R9. Wave approach to brightness temperature from a bounded layer of random discrete scatterers (Y. Q. Jin), Technical Report No. EWT-RS-71-8412, MIT, 1984.

T1. Lin, Sching Lih, "Microwave thermal emission from a periodic surface," S.M. Thesis, May 1983.

T2. Park, Dongwook, "Passive remote sensing of layered random media with strong permittivity fluctuations," S.M. Thesis, May 1984.

T3. Shin, Robert Tong-ik, "Theoretical models for microwave remote sensing of earth terrain," Ph.D. Thesis, September 1984.

T4. Jin, Ya-qiu, "Strong fluctuation theory for a bounded layer of random discrete scatterers," Ph.D. Thesis, January 1985.

T5. Lee, Jay Kyoon, "Electromagnetic wave propagation and scattering in layered anisotropic random medium," Ph.D. Thesis, January 1985.

DISCRETE RANDOM MEDIA TECHNIQUES FOR MICROWAVE MODELING OF VEGETATED TERRAIN

Roger H. Lang

Referred Publications

Electromagnetic Backscattering from a Layer of Vegetation: A Discrete Approach, with J.S. Sidhu, IEEE-GE-21, p. 62-71, 1983.

Scattering from Arbitrarily Oriented Dielectric Disks in the Physical Optics Regime, with D.M. LeVine, R. Meneghini, S.S. Seker, JOSA, 73, p. 1255-1262, 1983.

Scattering From Thin Dielectric Disks, with LeVine, Schneider and Carter, NASA TM 86155, 1984. To be submitted to IEEE-APS, 1985.

Microwave Inversion of Leaf Area and Inclination Angle Distributrions from Backscattered Data, with H.A. Saleh, submitted for publication in Special Issue of IEEE Trans. on GeoSci. and Remote Sensing, 1985.

Vector Solution for the Mean Electromagnetic Fields in a Layer of Random Particles, with Seker and LeVine, to be submitted to Radio Science, 1985

Presentations

Backscattering from a Vegetation Layer - A Multiple Component Model, with LeVine, presented at URSI, Boulder, CO, 1983.

Mean Wave Propagation in a Trunk Dominated Forest, with A. Schneider and S. Seker, presented at IEEE/URSI Symposium, Houston, TX, 1983.

Backscattering from a Vegetation Layer-Coherent and Incoherent Models, presented at URSI Commission F Symposium on Microwave Signatures in Remote-Sensing, Toulouse, France, 1984.

Discrete Scattering Models for Remote Sensing, seminar at NASA Goddard Space Flight Center, Greenbelt, MD, 1984.

Scattering from Thin Dielectric Disks with D. LeVine - presented at IEEE/APS URSI Meeting, Boston, MA, 1984.

Inverse Solution for a Slab of Random Dielectric Discs: Orientation and Area Distributions, with H. Saleh, to be presented at IEEE/APS URSI Meeting, Vancouver, Canada, 1985.

The Relationship Between the Field Correlation Function and the Specific Intensity, with A. Ghuniem, to be presented at IEEE/APS URSI Meeting, Vancouver, Canada, 1985.

MEASURING AND MODELING OF THE DIELECTRIC PROPERTIES AND ATTENUATION OF VEGETATION

Fawwaz T. Ulaby

Refereed Journal Publications

Ulaby, F. T., and R. P. Jedlicka, "Microwave Dielectric Properties of Plant Materials," IEEE Transactions on Geoscience and Remote Sensing, GE-22, pp. 406-414, July 1984.

Brunfeldt, D. R., and F. T. Ulaby, "Measured Microwave Emission and Scattering in Vegetation Canopies," IEEE Transactions on Geoscience and Remote Sensing, GE-22, pp. 520-524, November 1984.

Ulaby, F. T., M. Razani, and M. C. Dobson, "Effects of Vegetation Cover on the Microwave Radiometric Sensitivity to Soil Moisture," IEEE Trans. on Geoscience and Remote Sensing, GE-21, N.1, pp. 51-61, January 1983.

Brunfeldt, D. R., and F. T. Ulaby, "Microwave Emission from Row Crops," submitted to IEEE Trans. on Geoscience and Remote Sensing.

Ulaby, F. T., and E. Wilson, "Microwave Attenuation Properties of Vegetation Canopies," submitted to IEEE Trans. Geoscience and Remote Sensing SRAEC Special Issue.

Allen, C. T., and F. T. Ulaby, "Modeling the Polarization Dependence of the Attenuation in Vegetation Canopies," submitted to IEEE Trans. on Geoscience and Remote Sensing.

Symposia

Jedlicka, R. P., and F. T. Ulaby, "Measurements of the Microwave Dielectric and Attenuation Properties of Plants," National Radio Science Meeting (URSI Commission F), University of Colorado, Boulder, January 5-7, 1983.

Brunfeldt, D. R., and F. T. Ulaby, "Measured Microwave Emission and Scatter in Vegetation Canopies," IEEE International Geoscience and Remote Sensing Symposium (IGARSS '83), San Francisco, California, August 31 - September 2, 1983.

Ulaby, F. T., "Microwave Properties of Vegetation Canopies: An Overview," International Colloquium on Spectral Signatures of Objects in Remote Sensing, Bordeaux, France, September 13-16, 1983.

Ulaby, F. T., R. P. Jedlicka, and C. T. Allen, "Measurements of the Sources of Scatter from Vegetation," Microwave Signatures in Remote Sensing (URSI Commission F), Toulouse, France, January 16-20, 1984.

Brunfeldt, D. R., F.T. Ulaby, and M. C. Dobson, "Active and Passive Observations of Vegetation Canopies," Microwave Signatures in Remote Sensing (URSI Commission F), Toulouse, France, January 16-20, 1984.

Allen, C. T., and F. T. Ulaby, "Modeling the Polarization Dependence of the Attenuation in Vegetation Canopies," IEEE International Geoscience and Remote Sensing Symposium (IGARSS '84) , Strausbourg, France, 27-30 August, 1984.

Brunfeldt, D. R., and F. T. Ulaby, "The Effects of Row Direction on Microwave Emission from Vegetation Canopies," IEEE International Geoscience and Remote Sensing Symposium (IGARSS '84), Strasbourg, France, 27-30 August, 1984.

PUBLICATIONS AND PRESENTATIONS
Determination of Backscattering Sources in Various Targets
R.K. Moore, Principal Investigator

1. Refereed Journal Articles

"Determination of Backscatter Sources in Surface Type Targets," R. Zoughi, R.K. Moore, L.K. Wu, F.T. Ulaby and A. Afifi, to be published in International Journal of Remote Sensing, 1985.

"Preliminary Results on the Determination of the Sources of Scattering from Vegetation Canopies at 10 GHz," L.K. Wu, R.K. Moore, R. Zoughi, F.T. Ulaby and A. Afifi, to be published in International Journal of Remote Sensing, 1985.

"SOURCESCAT: A Very-Fine-Resolution Radar Scatterometer," R. Zoughi, L.K. Wu and R.K. Moore, submitted to Microwave Journal, 1984.

2. Conference and Symposia Presentations

"Measurements of the Sources of Scatter from Vegetation," R.K. Moore, R. Zoughi, L.K. Wu, A. Afifi and F.T. Ulaby, presented at the URSI Specialists Symposium, Toulouse, France, January 1984.

APPENDIX

APPENDIX A. THIRD ANNUAL PRINCIPAL INVESTIGATOR WORKSHOP-- INVITATION LETTER AND AGENDA

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland
20771

NASA

Reply to Attn of: 623

NOV 30 1984

Dear Colleague:

Trivia question No. 1: "Which state of the original thirteen was the sixth admitted to statehood in 1788 and has a land area of 8,257 square miles?" Trivia question No. 2: "Which city in that state has well-known institutions of higher learning that were established in 1636 and 1861?" Trivia question No. 3: "When and where is the third annual SRAEC PI's meeting going to be held?" The annual gathering of the NASA Fundamental Remote Sensing Science Research Program's Scene Radiation and Atmospheric Effects Characterization Project's principal investigators is not a trivial event, this year especially, as each of you will be reporting the results and significance of three years of research! This letter is to 1) confirm the time and place for the meeting, 2) advise you concerning follow-up communications concerning the meeting, and 3) inform you of the preparations that you should make for this meeting.

As you have been informed via telecon, the third annual SRAEC PI's meeting will be held on the campus of the Massachusetts Institute of Technology in Cambridge during the last three days of January (29, 30, and 31) 1985. Dr. Jin Kong has graciously offered to host this meeting and is making the necessary local arrangements and finalizing the agenda for the meeting. Dr. Kong will be sending you further details concerning these items within the next few days. It might be useful to mention at this time however that a special hotel room rate has been negotiated and a block of rooms have been reserved for our group at the nearby Sonesta hotel.

I'm very pleased that at this time it appears that we may have a 100% P.I. participation at this meeting. I want to encourage you to make every effort to attend the entire three days of the meeting. We are planning to take a group photo at this meeting and I would like everyone in the picture. More important, however, is that we want full participation in the results reporting and research issues discussions.

This meeting, and your individual reports, will be focused on summarizing the significant contributions that these past three years of fundamental research have made to the remote sensing scientific community. In addition to learning about the more technical details and specific progress that has been made in your more focused research activity, we all together need to be able to summarize the new insights that have been gained, the remote sensing problems that have been solved and, in general, what benefit this project has provided to NASA and the remote sensing and broader scientific communities. We need to collectively address a few key research issues and what are the new research priorities, based on what we have learned. Thus, we need to spend some "quality time" that will help both direct and defend this program.

In addition to bringing your body and mind to this meeting, I need you to bring with you a brief written summary of your research that will be compiled with the summaries from all of the PIs into an annual report. This year I am asking for a single written report that falls somewhere between the "Investigation Summary Results Abstract" and the "Investigation Synopsis" that you prepared last year. I need a succinct report that is introduced by a paragraph on the justification, goals and objectives for your research (the broader two or three year plan). This should be followed by a paragraph describing your technical or experimental approach. A discussion of the research results should then follow and can use up to three key figures to illustrate your findings. The final one or two paragraphs should highlight the significance of your results and (briefly) what the next major step should be in the logical progression of your research focus. This report should be a minimum of two and a maximum of four single-spaced typewritten pages, excluding figures. Figures should be suitable for reproduction (clearly readable) at one-half of full size as submitted to me on 8 1/2" x 11" paper. As the heading at the top of the first page you should include the descriptive title of your study (all capital letters), your name (first) and then any co-investigator's names, and your institutional affiliation beneath the names.

On a separate page (typed single-spaced with a double space between entries) you should include your list of publications and presentations that have resulted from your funding from the SRAEC Project. You should give your study title and your name (as PI) only at the top of this page followed by a separate listing of 1) refereed journal publications and 2) symposia and conference presentations.

Please adhere to the limits given above in preparing your report. Remember that this report is not a journal paper but rather is intended for a less technical readership (i.e., scientists from other disciplines and research program managers) and should be written to provide an interesting overview of your work. Your journal papers are available for anyone who needs or wants all the details and highly specific/technical results. Help me put together a report that will enable us to keep this program alive and well within NASA during this era of significant government budget cutting.

Your oral report should be prepared as last year, allowing 15-20 minutes for presentation and 10 minutes for discussion. One final topic concerns the IEEE Transactions on Geoscience and Remote Sensing "Special Issue on Scene Radiation and Atmospheric Effects Characterization". For various

reasons the communication concerning the deadlines for this special transactions has not been what it should have been. Nevertheless, the current "deadline" for you to submit five copies of your paper (to Bob Murphy) for the September 1985 specical issue is December 15, 1984 (moved back from the original September deadline). However, I have spoken with the editor and he has indicated that they can be submitted later than this date but the probability of their being reviewed, revised and re-submitted in final form in time for this special issue decreases with each week past this deadline. Probably early January will be sufficient time. Please submit your paper as soon as possible, as we would like a paper from each one of the PIs in the SRAEC project.

Thank you for your eagerness to participate and future help in making this year's meeting a success. If you have further questions please feel free to call me at (301) 344-9186 or Jin Kong at (617) 253-5625, as appropriate. I look forward to seeing you again in January.

Sincerely,

Donald W. Deering
Earth Resources Branch
Laboratory for Terrestrial Physics

P.S. Answers to Trivia Questions:
1. Massachusetts
2. Cambridge (Harvard, MIT)
3. January 29-31, 1985; Cambridge, MA

Meeting Agenda

Third Annual Meeting of the NASA Fundamental Research Scene Radiation and Atmospheric Effects Characterization

January 29–31, 1985

Tuesday, January 29, 1985

09:00-09:20	MIT Welcome (Jon Allen)
09:20-09:50	NASA Welcome and Meeting Objectives (Don Deering)
09:50-10:30	Invited Speaker Ken Hardy on applications of satellite data for meteorological analysis
10:30-11:00	Coffee Break
10:00-12:00	PI Reports (Gerstl,Diner)
Lunch	
13:00-15:00	PI Reports (Fraser,Pearce,Badhwar,Vanderbilt)
15:00-15:30	Coffee Break
15:30-17:00	PI Reports (Kimes,Smith,Strahler)
18:00	Reception, MIT Faculty Club

Wednesday, January 30, 1985

09:00-10:30	PI Reports (Norman,Paris,Ulaby)
10:30-10:45	Coffee Break
10:45-12:15	PI Reports (Fung,Kong,Moore)
Lunch	Photo opportunity
13:00-15:00	PI Reports (Lang,Conel,Irons,Kahle)
15:00-15:30	Coffee Break
15:30-16:00	Canopy model inversion (Goel)
16:00-17:30	Presentation and discussion on proposed artificial canopy experiment (Chair: Gerstl)

Thursday, January 31, 1985

09:00-09:30	Invited Speaker Dave Staelin on Retrieval Techniques for Atmospheric Profiling
09:30-10:00	Report on ISLSCP-FIFE (John Norman)
10:00-10:30	NASA Headquarter Management Perspective (Bob Murphy)
10:30-11:00	Coffee Break
11:00-12:00	Discussion on project accomplishments and future research directions (Chair: Smith and Ulaby)
Lunch	
13:00-14:30	Research topic discussions and working papers
14:30-15:00	Coffee Break
15:00-17:00	Written summary for project accomplishments and future research recommendations

APPENDIX B. THIRD ANNUAL MEETING PARTICIPANTS--LIST AND PHOTO

THIRD ANNUAL MEETING OF THE NASA FUNDAMENTAL RESEARCH
SCENE RADIATION AND ATMOSPHERIC EFFECTS CHARACTERIZATION

January 29-31, 1985

PARTICIPANT LIST

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ORIGINAL PAGE IS
OF POOR QUALITY

Figure B-1. Participants at the Third Annual SRAEC PI Workshop on the campus of MIT on January 30, 1985. The participants are: (left to right) Reza Zoughi, Vince Gutschick, Don Deering, Jim Smith, Dan Kimes, Mary Jane Bartholomew, Fawwaz Ulaby, Roger Lang, Gautam Badhwar, Clemes Simmer, John Norman, Dave Diner, Vern Vanderbilt, Siegfried Gerstl, Naren Goel, Bill Pearce, Ann Kahle, Dick Moore, Jack Paris, Jim Irons, Adrian Fung, Jim Conel, David Staelin, Jin Kong, Alan Strahler, Bob Fraser.

APPENDIX C. MESSAGE TO PIs FROM DR. MURPHY

Posted: Thu Jan 31, 1985 10:28 AM EST Msg: XGIF-1963-1511
From: REMURPHY
To: DDEERING
Subj: RE: Message to SRAEC PIs
DON, Please read this note to the troops for me.

I am sorry that I am not able to be with you at the 4th (can it really be the 4th?) meeting of the SRAEC principal investigators. My new job has had me on the road more than half of the time. I just couldn't do this one, both in terms of the backlog at my desk and the impact on my family.

I just returned from Geneva where I secured the blessing of the World Meteorlogical Organization for the International Satellite Land Surface Climatology Project (better known to its progeniters as ISLSCP). This was a major step forward in the process of orienting NASA's program to scientific goals. There is a description of ISLSCP activities in the current Space Science and Applications Notice which you should all have received. If you didn't see it, Don Deering, Bob Fraser and John Norman know everything you need to know about ISLSCP. There are also several reports by working groups which are available from Ron Witt (for retrospective studies) or Piers Sellers (for the field experiments). Both are at Goddard. That program should provide some of the focus for the application of the your SRAEC efforts in the future. (You may recall that I said that cultural crops where not the focus anymore. Here is one of the alternatives.)

We are attempting to generate some other foci for the program. Berrien Moore of the University of New Hampshire is chairing a subcommittee of the Earth System Sciences Committee which deals with the Land Processes. We had a very successful meeting at UNH in November, and Jim Smith is organizing a follow-on meeting next month at Goddard to discuss measurement and modeling strategies. The Berriens committee meets again in March at Oregon State. Out of these meetings I expect some more fruitful directions.

The work of the SRAEC group will be at the center of all that we will be doing. I hope to have a meeting of all PI's in the total program sometime later this year so that all can benefit from the type of interaction you are having now.

A not quite pleasant topic to bring up is the IEEE special issue. A few of you (and you know who you are!) still owe me your papers. Soon! (please?) What we have so far looks great.

To return to pleasant things, I will be looking forward to receiving your renewal proposals over the next few months. There is much left to do, and you guys can do it. If you have questions about the nature of desireable work you can talk with Don or me. I will conduct the peer review from NASA HQ, but will do so in close coordination with Don and I will look to him for programatic guidance.

As for the future of the Land Processes Program, I think that it looks good. This year we are (I hope) at the nadir of our funding with 5M$ less than fiscal year 84. Total useful funding this year is about 12 M$ for Geology,

Hydrology, Terrestrial Ecosystems, Remote sensing Science (thats you) and Applications. For next year, we have received high priority within NASA for an augmentation. Listen to President Reagan's budget message next week and see if he mentions us by name (HA!).

If we do receive that augmentation their can be some improvement in our average funding levels as well as the addition of new activites and some further upgrading of facilities. Things like the artificial canopy can proceed out of our existing funding base if someone redirects their curent work if we don't get the augmentation, or it can be an add on if we get it. (This, of course, asumes that it passes muster in terms of the programatics and peer review. Your input through Don from this workshop will shape the programatics; peer review will be according to pur usual capricious standards!)

As you know, we had a successful shuttle flight this past year. While we got only a fraction of the SIR-B data that we hoped for, there is much good science ahead in the analysis of it. SIR-B will be reflown in early 1987 and SIRC will follow about a year later. We are hopeful of flying the Shuttle Imaging Spectrometer Experimet (SISEX) also in the 80's. Our aircraft capabilities are gradulaly being upgraded and we know have semi- operational bidirectional measurement capabilities from the air as well as the Airborne Imaging Spectrometer (AIS) , the Thermal Imagging Mapping Spectrometer (TIMS), a quad-pol SAR and a 4 beam L-Band pushbroom radiometer.

I know I've left somethings out, and I am typing this while I am in transit to yet another meeting. So please excuse the rambling and incomplete nature of it. Keep up the good work. I hope to see you next year if not sooner. Perhaps at the IGARS meeting at UMASS.

Bob

BIBLIOGRAPHIC DATA SHEET

1. Report No. TM # 86234	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Fundamental Remote Sensing Science Research Program--1985 Summary Report of the Scene Radiation and Atmospheric Effects Characterization Project		5. Report Date Sept. 1985 6. Performing Organization Code Code 623
7. Author(s) D.W. Deering		8. Performing Organization Report No.
9. Performing Organization Name and Address Earth Resources Branch NASA Goddard Space Flight Center Greenbelt, Maryland 20771		10. Work Unit No. 11. Contract or Grant No. 13. Type of Report and Period Covered TM
12. Sponsoring Agency Name and Address NASA Headquarters Washington, DC		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The Scene Radiation and Atmospheric Effects Characterization (SRAEC) Project was established within the NASA Fundamental Remote Sensing Science Research Program to improve our understanding of the fundamental relationships of energy interactions between the sensor and the surface target, including the effect of the atmosphere. The current studies are generalized into the following five subject areas: optical scene modeling, earth-space radiative transfer, electromagnetic properties of surface materials, microwave scene modeling, and scatterometry studies. This report has been prepared to provide a brief overview of the SRAEC Project history and objectives and to report on the scientific findings and project accomplishments made by the nineteen principal investigators since the project's initiation just over three years ago. This annual summary report derives from the most recent annual principal investigators meeting held January 29-31, 1985.

17. Key Words (Selected by Author(s))	18. Distribution Statement
scene radiation atmospheric effects microwave optical-reflective	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
unclassified	unclassified		

*For sale by the National Technical Information Service, Springfield, Virginia 22151.